THE JOURNAL

OF

"The Royal Aeronautical Society"

with which is incorporated "The Institution of Aeronautical Engineers"

Edited for the Council by J. LAURENCE PRITCHARD, Hon. Fellow

No. 202. OCTOBER, 1927. Vol. XXXI.

NOTICES

Amalgamation

The Council wish to place on record their great gratification at the happy termination of the long series of negotiations between the Institution of Aeronautical Engineers and the Society, resulting in a formal agreement for amalgamation. Steps are being taken, in accordance with the terms of amalgamation, to alter the rules and to deal with other matters which are a necessary resultant of the negotiations. A short account of the negotiations leading up to the amalgamation, together with the terms agreed upon, were given on pages 886-889 of the September Journal.

Seven members of the old Council have resigned to allow the new members representing the Institution of Aeronautical Engineers to be co-opted, and to make the new interim Council truly representative of the amalgamated body. The seven retiring members, to whom the Society owe much for their energy and zeal on its behalf, for their freely given advice and assistance over the details of the amalgamation, and finally for their action in making way for the new Council members, are as follows:—

Sir Mackenzie D. Chalmers, K.C.B., C.S.I.
Captain G. T. R. Hill, M.C., M.Sc., F.R.Ae.S.
Mr. J. E. Hodgson.
Mr. H. B. Irving, A.F.R.Ae.S.
Major G. H. Scott, C.B.E., A.F.C., F.R.Ae.S.
Mr. H. C. Watts, D.Sc., F.R.Ae.S.
Mr. R. McKinnon Wood, F.R.Ae.S.

The new interim Council, which will function until March 31st, 1928, follows. Those names marked with an asterisk are new members of Council appointed by the Institution of Aeronautical Engineers:—

Captain P. D. Acland.
*Mr. M. L. Bramson, A.C.G.I., A.F.R.Ae.S., M.I.Ae.E.
Mr. Griffith Brewer, F.R.Ae.S.
Wing Cdr. T. R. Cave-Browne-Cave, C.B.E., A.M.I.Mech.E., A.M.I.N.A., F.R.Ae.S.
Mr. A. E. L. Chorlton, C.B.E., M.Inst.C.E., M.I.Mech.E., A.F.R.Ae.S.
Mr. C. R. Fairey, M.B.E.
*Captain F. T. Hill, A.F.R.Ae.S., M.I.Ae.E.
*Mr. N. J. Hulbert, A.M.I.Ae.E.
*Captain A. G. Lamplugh, A.F.R.Ae.S., M.I.Ae.E.
Major A. R. Low, F.R.Ae.S.
Mr. W. O. Manning, F.R.Ae.S.
Major R. H. Mayo, O.B.E., F.R.Ae.S.
*Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.I.Ae.E., M.P.
Lieut.-Colonel M. O'Gorman, C.B., D.Sc., F.R.Ae.S.
Mr. F. Handley Page, C.B.E., F.R.Ae.S.

*Mr. F. R. Simms, M.I.Mech.E., M.I.A.E., M.I.Ae.E.
Mr. T. O. M. Sopwith, C.B.E., F.R.Ae.S.
Air Vice-Marshal Sir Vyell Vyvyan, K.C.B., D.S.O.
Mr. H. E. Wimperis, C.B.E., F.R.Ae.S.
*Mr. L. A. Wingfield, M.C., D.F.C.
Ex-officio: Mr. J. E. Hodgson, *Hon. Librarian.*
Major D. H. Kennedy, O.B.E., F.R.Ae.S., *Hon. Treasurer.*

As a result of the amalgamation certain changes will be noticed in the appearance of the Journal, chiefly due to the change in title.

The attention of all members is drawn to the list of publications of the Institution of Aeronautical Engineers on pages 902-904, which are now available.

Journal

On and after January 1st, 1928, the price of the Journal will be increased to 3s. 6d. per copy, or 3s. 9d. post free. The subscription per annum will be £2 4s. 6d. post free. Owing to the increasing number of papers read before the Society and the increasing number of technical articles being published in the Journal, its size will be considerably greater than it has been in recent years.

Chairman

Colonel the Master of Sempill, A.F.C., A.F.R.Ae.S., having been unanimously re-elected by the whole Council, entered upon his second year of office as Chairman of the Society on October 1st, when Air Vice-Marshal Sir Vyell Vyvyan, K.C.B., D.S.O., assumed office as Vice-Chairman.

Associate Fellowship

The papers set for the Associate Fellowship Examination held on September 20th, 1927, are printed on pages 989-990 of this issue. Copies of papers set in former years may be had on application to the Secretary.

Schneider Trophy

Letters of congratulation have been written by the Chairman, on behalf of the Council, to Sir Samuel Hoare, the Air Minister, The Supermarine Aviation Co., Ltd., and Messrs. Napier, Ltd., on the occasion of the winning of the Schneider Trophy for Great Britain by Flight Lieut. S. N. Webster at an average speed of 281 m.p.h.

Forthcoming Arrangements

Thursday, October 6th, 6.30 p.m.—Inaugural Lecture by Mr. F. Handley Page, C.B.E., F.R.Ae.S.: "Aviation."

Thursday, October 13th, 6.30 p.m.—Squadron Leader T. H. England, D.S.C., A.F.C.: "The Practical Side of Performance Testing of Aircraft."

Thursday, October 20th, 6.30 p.m.—Mr. M. L. Bramson, A.C.G.I., A.F.R.Ae.S., M.I.Ae.E.: "Safety Devices for Aircraft."

Thursday, November 3rd, 7.45 p.m.—Joint Meeting with the Institution of Automobile Engineers. Mr. H. B. Taylor A.F.R.Ae.S.: "High Speed Compression Ignition Research."

All lectures will take place at the Royal Society of Arts, 18, John Street, Adelphi, W.C.2.

Publications of Institution of Aeronautical Engineers

The following is a list of papers published by the Institution of Aeronautical Engineers and now available from the Offices of the Society at the prices marked :—

MINUTES OF PROCEEDINGS. 1s. 6d. net. Post free 1s. 8d.

1923.

No. 3. "Aeroplane Design," by Mr. H. P. Folland, F.R.Ae.S., M.B.E. (Honours Member).

No. 4. "Constructional Design of Aeroplanes." A paper in three sections by Mr. C. W. Tinson, A.F.R.Ae.S. (Member).
"Oleo Undercarriage Design," by Mr. G. H. Dowty, A.M.I.A.E. (Associate Member).

No. 5. "Experimental Data without a Wind Channel," by Major O. T. Gnosspelius, A.C.G.I., A.F.R.Ae.S. (Honours Member).
"Gliding and Gliders at Itford." A Discussion led by Mr. W. O. Manning.
"Wind Tunnel Work at the National Physical Laboratory," by Mr. W. L. Cowley, A.R.C.Sc., D.I.C., Wh. Sch. (Member).
Report of Fifth Annual Meeting with Presidential Address and Lecture on "Aerial Photography" by Lieut.-Col. J. T. C. Moore-Brabazon, M.C., M.P.

No. 6. "Some Controversial Points in Aircraft Detail Design," by Mr. F. T. Hill, B.Sc., Wh.Ex., A.F.R.Ae.S. (Member).
"Low-powered Flying," by Squadron Leader M. E. A. Wright, A.F.C.
"Some Aspects of an Attempt to Fly Round the World," by Major W. T. Blake (Associate Member).

1924.

No. 7. "Welded Steel Tube Construction and the Development of Cantilever Wings," by Mr. A. H. G. Fokker.

No. 8. "Three-ply and its Uses in Aircraft Construction," by Capt. R. N. Liptrot, B.A.
"The Soaring Flight Question," by Dr. E. H. Hankin, M.A.

No. 9. "The Loth Leader Cable System for Electrical Steering of Aeroplanes," by Mr. John Gray, B.Sc., M.I.E.E.
"Reminiscences of the Early Days of Aviation at Brooklands," by Mr. R. L. Howard-Flanders, A.F.R.Ae.S., A.M.I.Mech.E. (Honours Member).

No. 10. "Some Problems in Connection with the Structure of Rigid Airships," by Lieut.-Col. V. C. Richmond, O.B.E., B.Sc.
"Low-powered Flying," by Mr. W. O. Manning, A.F.R.Ae.S. (Honours Member).

No. 12. "Braided Rubber Shock-absorber Cord for Aircraft," by Mr. L. Rowland, B.Sc., A.M.I.C.E.
Sixth Annual Meeting, 1924, with Presidential Address by Lieut.-Col. J. T. C. Moore-Brabazon, M.C., M.P., and Paper on "Empire Communications," by Mr. A. H. Ashbolt.

1925.

No. 13. "Commercial Airship Design," by Commander F. L. M. Boothby, C.B.E.
"Steel versus Lighter Alloys," by Colonel N. Belaiew, C.B., M.I.Met., etc. (Member).

No. 14. "The History and Evolution of the Avro Training Machine," by Mr. R. J. Parrott, A.C.G.I. (Honours Member).

No. 15. "A Few Experiments with Shock-absorbing Hulls for Flying Boats," by Lieut. N. A. Olechnovitch (Member).
"The Position of the Airship in Aerial Transport," by Lieut.-Commander C. D. Burney, C.M.G., M.P., R.N. (ret.).
"Lessons of 1924," by Captain W. H. Sayers (Honours Member).

No. 17. "Photo-elastic Methods of Measuring Stress," by Prof. E. G. Coker, D.Sc., F.R.S.
"Flying in Australia," by Mr. H. L. J. Hinkler.

1926.

No. 18. "Some Aspects of Full Scale Experiments," by Mr. C. Howarth, A.F.R.Ae.S. (Member).
"The Care and Maintenance of Machine Tools as an Important Factor in Workshop Routine," by Lieutenant N. Olechnovitch, M.E. (Member).

No. 19. "Practical Flying," by Mr. M. L. Bramson, A.C.G.I. (Member).
"The Metal Construction of Aeroplanes—its Advantages—its Present State—its Future," by M. E. DeWoitine.

MONTHLY JOURNAL. 2s. net. Post free 2s. 2d.

1927.
Jan. "Metal-clad Rigid Airship Development," by Mr. Ralph H. Upson, M.S.A.E. (Hon. Member).
"Some Reminiscences of Ten Years Ago," by Mr. Lawrence S. Wingfield, M.C., D.F.C. (Associate, Hon. Solicitor).
Feb. "Unsolved Aeronautical Problems," by Mr. M. L. Bramson, A.C.G.I., A.F.R.Ae.S. (Member).
"Aircraft Alighting and Arresting Mechanisms," by Mr. G. H. Dowty, A.F.R.Ae.S. (Member).
Mar. "Wind Structure in Relation to Air Navigation," by Captain F. Entwistle, B.Sc.
"Some Practical Points in the Structural Design of Aircraft," by Dr. A. P. Thurston, D.Sc., M.B.E., M.I.Mech.E., F.R.Ae.S., M.I.A.E. (Hons. Member).
April. "Some Notes on the Possibilities of Progress in Aviation," by Mr. A. G. von Baumhauer.
"Air Photography Apparatus," by Mr. F. S. Barton, M.A., F.Inst.P.
May. "Some Experiments on the Effect of Repeated Stresses on Materials," by Prof. F. C. Lea, D.Sc., M.Inst.C.E., M.I.Mech.E.
"Some Notes on the Design of Airscrews," by Capt. F. S. Barnwell, B.Sc., O.B.E., A.F.C., A.F.R.Ae.S. (Hons. Member).
June. "Some Commercial Aspects of Air Surveying," by Major H. Hemming, A.F.C., F.R.G.S., A.F.R.Ae.S. (Director of the Aircraft Operating Co., Ltd.).
"Aviation in Australia," by Flight-Lieutenant J. Renison Bell, R.A.A.F.
July. "Flying for Air Survey Photography," by Capt. F. Tymms, M.C.
"Portable Hangars," by Major H. N. Wylie, B.Sc., F.R.Ae.S.
"A Summary of the Law in Relation to Aerial Navigation," by Mr. Lawrence A. Wingfield, M.C., D.F.C. (Honorary Solicitor of the Institution).
Aug. "Heat-resisting and Non-corrodible Steels," by Mr. S. A. Main, B.Sc., F.Inst.P. (of the Hadfield Research Laboratories, Sheffield).
"The Application of Insecticides by Aeroplane," by Mr. Dudley Wright (Associate Member).
Sept. "Some Further Practical Points in the Structural Design of Aircraft," by Dr. A. P. Thurston, D.Sc., M.B.E., etc. (Hons. Member).
"Notes on Seaplane Design," by Commander J. C. Hunsaker (C.C.), U.S.N., D.Sc., Hon.F.R.Ae.S., Hon.M.I.Ae.E.

J. LAURENCE PRITCHARD, *Secretary.*

PROCEEDINGS

TWELFTH MEETING, SECOND HALF, 62ND SESSION

The Twelfth Meeting of the Sixty-Second Session of the Royal Aeronautical Society was held in the Theatre of the Royal Society of Arts, 18, John Street, Adelphi, W.C.2, on Thursday, May 4th, 1927, when Captain T. Neville Stack read a paper on "To India by Light Aeroplane." Colonel the Master of Sempill, Chairman of the Society, was in the chair.

Colonel the MASTER OF SEMPILL, introducing the Lecturer, said: This evening we have come here full of enthusiasm to listen to Captain Stack's personal account of the splendid flight he made, accompanied by Mr. Leete, to India by light aeroplane. You will recollect that Sir Samuel Hoare, when introducing the Air Estimates in the House of Commons, referred to the fact that in the middle of the desert he had met Captain Stack and Mr. Leete on their flight to India.

In these days when many great flights are being undertaken, mostly by foreign countries, it is most refreshing to see what an enormous success this private venture has been.

You will probably recollect that, not so long ago, the Government organised a Light Aeroplane Competition. The de Havilland Company, feeling quite certain that the conditions of the competition would not lead to the production of a suitable type of light aeroplane, refused to enter, and set out on their own to produce what they believed would be a suitable machine. The result has been eminently successful and the Moth, with its Cirrus engine, designed by Major Halford, has earned fame for itself throughout the world.

To-day we are undoubtedly impressed with this flight, and I would suggest that in later days the account of this venture, if put into book form, will be regarded as a classic, just as books telling of ventures of past centuries are so regarded to-day.

BY LIGHT AEROPLANE TO INDIA

BY CAPTAIN T. MELVILLE STACK.

Reason for the Flight

1. In order to create a record for this type of aeroplane—that is to say, a "long distance flight."
2. To prove reliability of British aero engines and aeroplanes.
3. To popularise the light aeroplane and demonstrate how, without any great preorganisation or any financial backing, it is possible for an owner pilot to make a big tour in a standard aeroplane.

The Machines

Standard Moths powered with Mark II. Cirrus engines, only modification being an extra petrol tank in place of passenger. Both tanks between them carrying petrol for eight hours or sufficient for a journey of 550 miles cruising with a ground speed of 70 m.p.h. This left us a very safe and large margin, as our longest hop without coming down was 450 miles.

Spares Carried per Machine

Four plugs; one complete set of piston rings; two sets of cylinder head gaskets; two exhaust and inlet valves complete with springs, etc.; two valve guides; two fulcrum posts; four rocker arms and pins; two spare carburetter jets; one float; one spare fine adjustment needle; one spare contact breaker and carbon brush; one spare propeller; two inner tubes; one small tin of dope, Acetone and Hermatite; one roll of adhesive tape; one insular tape; one piece of fabric; needles and cotton; one box of assorted nuts and bolts, split pins, washers; one small sheet of hallite for making washers and one puncture outfit; a roll of tools with emery cloth. This with our maps, a ruler and a celluloid protractor for navigational purposes, completed our equipment.

Personal Kit

To wear whilst flying—one pair flannel grey trousers with a thick sweater and thick socks, a mechanic's overall suit, a muffler, gloves, helmet and goggles, one suit, complete change of underclothing, several pairs of socks, one extra pair of shoes, one hat and the necessary toilet requisites, most of which fitted in a small attaché case.

The Start of the Journey

On the 16th November, after obtaining weather reports which were none too good, we decided, as we had to land at Lympne to clear Customs, to get there that day and cross the Channel the following morning, weather permitting.

The short hop to Lympne was rather uncomfortable on account of the bad visibility, rain and a strong wind which had increased so much that on landing at Lympne we would have been blown over but for the promptitude of Commander Deacon's ground staff, who were awaiting our arrival and the moment we landed managed to grasp our wing tips. Commander Deacon was kindness itself to us.

Owing to exceptionally bad weather we were detained $3\frac{1}{2}$ days. During this period we discovered much foreign matter in the petrol tank of my machine, which necessitated the taking down and cleaning out of the whole petrol and induction system. This at the very commencement of our journey, and to be found in machines straight from the workshops, was rather disheartening. After this experience we ran a little petrol out of the drain cocks of both our tanks every day in order to clear away any residue that may have collected there.

On to Paris

On the 20th we crossed the Channel and had to circle St. Inglevert Aerodrome, so that they could see us and report our safe crossing to Lympne, as we ourselves carried no wireless. Our way then lay S.S.E., passing Boulogne on our right, over Montreiul and the Forêt de Crecy, passed Abbeville, then Poix where we overtook a Farman Goliath of the French Airways, passed Beauvais where we encountered low clouds and rain, rather unpleasant, owing to hills and then on to Le Bourget, Paris.

We went through Customs formalities, looked to our machines, filled up and then went into Paris. We lived at the Rest House on the aerodrome and found everything most comfortable and convenient. We were detained here by gales of wind and rain and were unable to get away until after mid-day on the 22nd; the weather was so bad on the 21st as to prevent Imperial Airway flying.

On to Lyons

On the morning of 22nd conditions were too dud to make a start, but

were improving. Shortly after mid-day we received a weather report from the meteorological section stating that conditions would improve as we progressed further south, so we started off, but owing possibly to some unforeseen break in the weather the reverse happened and we really encountered during this journey some of the worst weather we experienced through the trip. Also on account of the wind increasing we were obliged to make a night landing at Bron Aerodrome, Lyons, without lights or flares, their lighting system having been crashed in a gale the day before. Had we known beforehand that there were no landing lights of any description we certainly would not have ventured on into the dark, but landed at one of the aerodromes or landing grounds en route. The aerodrome staff had received notification that we were on our way, but thought we had landed on one of the aerodromes between Dijon and Lyons, because the weather was so bad. We were delayed here again for two days by weather.

On to Marseilles

On the 24th we flew down the Rhone Valley to Marseilles. The scenery was beautiful but marred somewhat by the fact that the valley was flooded and scarcely a field in view fit to land on. The recognised landing grounds such as St. Rambert, d'Albon, Moullemar, Orange and Avignon were not flooded however and our way lay over or close to all of these. The weather was delightful and we landed at the aerodrome of Marignane, Marseilles, after 2 hours 40 minutes flying. Here we looked very carefully to our engines as the next day we had to fly many miles over mountainous country and sea.

On to Pisa

The next day, the 25th, we left for Pisa, setting a course across the mountains from Marignane to St. Raphael, where we struck the sea again and flew around the coast, passing Nice, Monaco, Mentone, Genoa, etc. The coast is extremely mountainous with only three landing grounds in about 200 miles. There is a very small and narrow foreshore or beach in places that one might possibly land on, but with certain damage to the machine. After four hours' flying we arrived at Pisa and found the aerodrome flooded with the exception of a small strip seven to eight yards wide and about 100 yards long that was not under water. We used this to land upon and taxied to the hangars through the water and mud. Here we had to undergo the usual Customs and after seeing to our machines were later taken to our hotel by the Commandante of the aerodrome.

Whilst in Italy we received every courtesy and assistance from the Italian Air Force, who did everything possible for our welfare and comfort.

On to Rome and Naples

The next morning, the 26th, we left Pisa for Rome; the Italians had some doubt as to the possibility of our taking off on account of the aerodrome being in such a bad state. They had stopped flying for some time as the ground was unfit, but luckily there was a fairly strong wind blowing and we managed to take off in a shower of mud and spray. We stayed that afternoon, night and nearly the whole of next day in Rome in order to see the place, then continued our journey to Capua, near Naples. We chose Capua instead of Naples on the advice of the Italians, for it is so much larger and altogether a better ground. Here we were very well received by the Italians, who were most hospitable and entertained us for three whole days on account of the weather conditions being most unfavourable for the continuation of our trip.

On to Sicily and Malta

On our way from Capua we flew over the edge of the crater of Mount

Vesuvius. This was at the time when the volcano was active and belching forth smoke and occasionally a red flame or glare. We had a very fine view of this spectacle in passing and then continued on down the coast (which is extremely mountainous) for a distance, then our course took us over the sea, leaving Stromboli on our right, to Sicily, over Messina, past Etna and so to Catania, where we landed for petrol, oil and lunch. At Catania also the Italian Air Force were extremely hospitable and tried hard to persuade us to stay for the night, but we were eager to take advantage of the fine day, and so after lunch, which was rather a long affair, pushed on to Malta, where we landed with about half an hour's daylight to spare. Needless to say we were glad to be amongst our own again. Here our machines were taken over by the R.A.F. and thoroughly tuned up for our hop across the Mediterranean Sea. Everyone at Malta was most kind and hospitable. We cannot thank enough His Excellency the Governor and Lady Congreve, Sir Roger Keys and Lady Keys for their kindness and all those who assisted us and made our enforced stay at Malta such a happy one. We were detained here for seven days by severe storms and bad weather.

On to Khoms

On the morning of December 8th we worked out our course and went off across the sea to Khoms in Tripoli, escorted for about 80 miles by Flight Lieutenant Newton in a Fairy seaplane. We felt very lonely when he turned back and shortly afterwards ran into low clouds and rain. The visibility became very bad and we saw no shipping whatsoever; on account of these conditions we were unable to see the N. African Coast until within about five to six miles from it. We had every confidence in our engines particularly as the experts at Malta had taken them in hand and pronounced most favourably on their condition and the fact that we had had no trouble so far, nevertheless we were glad to see land, for the sea crossing seemed ages. We struck land about one mile to the west of our objective, which was Khoms, flew over the town and landed on the aerodrome, which was marked with the name in large letters.

There is one large hangar here and a very small aerodrome staff. We were again most hospitably received by Italians, who helped us fill up that afternoon in readiness for an early start the following morning.

On to Benglazi

The next morning the 9th of December we started off for Benglazi, a trip of some 450 miles, part of which we understood (about 200) lay over hostile territory. The journey took us six hours, during which time we encountered much wind, low clouds and rain, causing us to fly for some 80 miles over the hostile territory at an altitude between 200 and 300 feet. We saw some encampments in passing, but no hostile demonstrations were evinced. At Benglazi we were welcomed by Mr. Palmer, the British Consul, and by Commandante Sala, the officer in command, who said he would be our mother-in-law and look after us. He was, and he did. All along the line the Italians treated us extraordinarily well.

On to Porto Bardia

Owing to gales and storms we were unable to leave Benglazi until the 11th, the weather was not then really favourable and the Italian officers tried to persuade us not to go, they themselves had washed out flying on account of the conditions. Still we determined to risk the weather and had a much rougher journey than we bargained for through thunder, rain, low clouds and strong gusty winds. We landed at Porto Bardia, in a storm, after four hours ten minutes flying, and were just saved from being blown over once more. Here we were again hospitably received.

On to Cairo

The next morning, the 12th, we flew to Cairo and made a comfortable journey with a following wind doing the 400 miles in four hours 50 minutes. We passed through one bad rain storm near the cultivation, being the only unpleasantness on this part of the trip. We were given a warm welcome at Heliopolis by the R.A.F., who as at Malta took us completely under their wing, which meant that we had nothing whatsoever to worry about. We stayed one day extra to look over the machines thoroughly and get them ready for the long desert trip to Baghdad. It was hardly necessary, the machines in spite of their buffeting were in tip-top condition and the engines running sweetly.

On to Baghdad

On the 14th at 7.30 a.m., we started off on our trip to Baghdad which was accomplished in three stages on account of strong contrary winds. Our way lay from Cairo, passed Ismalia, over the Suez Canal, through Palestine, over the Judean Hills and Dead Sea, leaving Jerusalem and Jericho on our left, thence to Ziza in Transjordania.

The journey so far had taken us 5 hours 25 minutes, and we had passed over two sand storms on our way. As it would not have been possible for us to have got even half way across the track to Baghdad on account of the strong headwind, before nightfall, we decided to spend the night at Aman with the R.A.F., who had kindly invited us. The next morning we discovered that one of Leete's magnetos had seized, which delayed our start for some time, but eventually started off with one functioning on his engine. After 5½ hours, flying through bad weather with a strong headwind, we arrived at Rutt Cal Wells. At one time there were only a few holes in the ground at this spot and perhaps an Arab encampment, now there is to be found a fortified hotel with every convenience hundreds of miles from the nearest civilisation.

We stayed the night and continued our journey in the morning. On our way we passed several motor convoys, a couple of which were bogged. Upon arrival at Baghdad we taxied to our respective squadrons 70 and 55, of which three years previously we had been members. Needless to say we were most heartily welcomed and well looked after. The depot did a very fine piece of work in cutting and driving a spocket for Leete's magneto, which carried him all the way through the remainder of the trip. People were full of praise for the two small machines that had crossed the desert track unescorted.

On to Basrah

On Xmas eve we continued our journey on to Basrah, where we spent Xmas and Boxing Day with 84 squadron at Sheba. It was a very cheery time and on the 26th we flew to Bushire in the Persian Gulf.

On to Bushire

We passed over the Great Oil Port of the Anglo Persian Oil Company at Abbadon across the flooded swampy area at the top of the Persian Gulf and across the corner to Bardar Dilan where Leete had a forced landing due to oily plugs. The manner in which he picked out the only piece of ground and the judgment shown in gliding to and landing on it was a remarkably fine piece of piloting. We rectified the trouble and continued on to Bushire. At this place we top overhauled both our engines in six days and were overtaken by Sir Samuel Hoare in the De Havilland Hercules. It was very pleasant meeting the party of the Hercules in such a remote spot and gratifying to learn of the kind interest shown by Sir Samuel Hoare and Lady Maud Hoare in our flight.

It was also most interesting to see the two latest types of De Havilland aeroplanes, the giant Hercules and the baby Moths in this out of the way corner of the world.

On to Yask and Charbar

Whilst overhauling at Bushire we discovered a crack in one of my cylinder heads, causing much loss of compression on one cylinder. This we managed to seal up more or less with hematite and so make a temporary repair.

We started up and got as far as Bardar Abbas where we lunched with the British representative, filled up with petrol and oil, put more hematite in the crack which was rapidly becoming larger and started off again for Yask, nearly 180 miles, which we reached at 4.40 p.m., having flown over 600 miles in 6½ flying hours. We were held up the next day by a very bad dust storm, but continued on the sixth to Charbar, a small native village with an Indo European Telegraph Station.

We were very well looked after by a Mr. Tomlinson, who is the British representative in that place.

On to Karachi

We were now only 450 miles from our goal and my cylinder head was causing quite an amount of anxiety. But after a little experimenting we managed to patch it up again and took off on the last stage of our voyage by air to India. We had a very strong crosswind to start with, and a very contrary one in the latter part of the journey. We also ran into dust which extended from the ground to 5,000 feet for at least 150 miles. We tried going above it, but this made matters worse for we were unable to see the ground at all beneath us, so we descended very low and followed the coast line which was just barely visible. Carrying on so, we narrowly missed a ridge of the Baluchistan Hills. This ridge is just at the frontier between Baluchistan and India. We crossed over and at last were in India, having accomplished that which we set out to do—namely, fly from London to India in a Moth light aeroplane, 5,541 miles over land, sea, mountains and deserts. We landed at Drigl Road Aerodrome, Karachi, where we were given a great reception. Wing-Commander Bone, C.B.E., D.S.O., and the officers of his command extended to us the utmost hospitality, making us guests of the mess for the remainder of our stay in Karachi and looking after our machine as only they know how. We were very pleased to receive a cable congratulating us from the Chairman on behalf of the Royal Aeronautical Society.

In conclusion I would like to say that a great deal of our success was due to the assistance we received from everyone with whom it was our good fortune to come in contact; the Italians who showed so much courtesy and kindness to a couple of strangers flying through their country; and the R.A.F. units at Malta, Egypt, Palestine, Iraq and India, who did everything to assist and extended such a wonderful hospitality as two wanderers scarcely dared to dream of. To them all once again our deepest appreciation and sincerest thanks.

Discussion

Air Vice-Marshal Sir W. S. Brancker: I do not think Captain Stack has really done himself justice in his interesting but very modest lecture. I can perhaps add a little to the history. I was one of the first to hear of his plans because he came to me and asked me to write a letter to say that, if he made a success of his flight to India, it would be a feat of national value. I was only too glad to give him what he wanted, and I gather that this letter was used successfully as a means of raising money for the flight.

I had the honour of following Captain Stack and Mr. Leete over the same course, but in a more stately fashion, on board the "Hercules" with three Jupiter engines and a crew of pilot, navigator and mechanic. Everywhere I landed I found an all-red trail of admiration and enthusiasm for their sporting effort. Not only were the British people everywhere delighted with this British enterprise, but French, Italians, Egyptians, Palestinians, Iraquis, Persians and

Indians were all sincerely impressed by the performance of these little machines and by the personalities of their pilots. There is no doubt that these two pilots have done a great deal of good in demonstrating what can be done by small aircraft. I hope that, now this good example has been set, all our young men with a little money will try to follow it, and in this connection it would be of value if Captain Stack would tell us how much his trip cost. It is just possible that the light aeroplane may one day be the cheapest method for a young man to get to India.

I should like to emphasise the value of the light aeroplane. I am just back from Tanganyika and Kenya—both countries very badly served by railways and where the roads are bad and in wet weather impossible in many places. In Kenya many settlers have to drive two or three days to reach Nairobi. With a light aeroplane, practically no one would be living more than two hours from Nairobi. I, personally, believe that, if an enterprising firm would send out two or three machines and demonstrate them in these countries, and others like them, they would find a very good market. Stack and Leete have proved that the light aeroplane is a factor of commercial value and not merely a toy for stunting and flying round aerodromes. As the Director of Civil Aviation, I wish to thank Captain Stack and Mr. Leete very heartily for the great credit which they have done British civil aviation throughout the world.

Mr. OPENSHAW: I should like to ask Mr. Stack whether he had any difficulty in obtaining supplies of oil and petrol, and whether the oil and petrol were of the right quality.

Mr. W. O. MANNING: I should like to congratulate Captain Stack on having demonstrated the possibility of taking a pocketful of spares and an attaché case and going off on a long flight successfully in a light aeroplane.

I should like to ask him first if he found that the machine gave any difficulty in taking-off in hot weather, and in connection with this question whether the weight when fully loaded was up to the maximum weight of the Moth as ordinarily flown?

I should also like to ask what type of propeller he used and whether it was of metal or wood. If it was of wood, I should like to know if he had any trouble with it in hot weather. He evidently had confidence in it as he apparently did not carry a spare one.

There is also the question of temperature effect on structure, and whether there was trouble owing to shrinkage of wooden members, etc. Had he to true up the machine often?

Then there is the question of rubber and its behaviour. Had the hot weather any effect on the tyres? Any information of that type would be of great interest to everyone and certainly assist technical progress, for light aeroplanes are bound to be used in hot countries, and it is of importance that as much information as possible should be available as to their behaviour under tropical conditions.

Mr. C. B. COLLINS: I notice that Captain Stack does not mention what type of compass he had fitted in his machine. The standard type of aperiodic compass is rather large for a light machine, and it would be interesting to know whether he used the standard or miniature type of compass, and if the latter whether it proved entirely satisfactory.

With regard to Porto Badia, this is a place we have not heard of at the Air Ministry as an organised landing ground. Would Captain Stack give us full details as to its size and the facilities available?

Mr. D. KITTEL: I think I can claim to be the first private owner to purchase a Moth, and after getting over a couple of good crashes in the early stages, I have used the machine regularly since. Last Easter I had the opportunity of combining a business and pleasure trip on the Continent, which proved very

enjoyable. In this way the Moth is a definitely useful machine and one can set off almost anywhere, provided there are sufficiently good landing spots at destination.

As the last speaker referred to the compass, I would also like to say a few words about this instrument. Having very little idea or experience of navigating I sometimes find, when steering a compass course, that I am out to the extent of a few miles, on a flight of two or three miles—that is to say, would be out if the direction were not corrected as the destination is reached. Of course, here in England, if you cannot recognise where you are, one can always come down and inquire, but if you are flying across the desert you cannot. I wonder if the inaccuracies are due to the way the course is worked out by the map, or whether my compass, a 5/17 which I believe is rather out of date, requires particularly skilful navigation. Will Captain Stack tell us what pattern was used on his machine?

Major C. C. Turner: What struck me while listening to the lecture was the very great advance which has been made in the last 18 years. In 1909-12 how little reliance could be placed upon machines of the same power as those of to-day. In those days people got lost flying across the Straits of Dover. Sir Sefton Brancker said that he hoped that the time would come when a great many young Britons would follow Captain Stack's lead. If I had heard that remark only 18 months ago I should have said, "Isn't it asking people to risk their necks?" Yet now that Captain Stack has accomplished this flight I feel that it is not too dangerous. Not many months ago I saw four Moths set out for Ireland. That was considered at the time by many people rather foolhardy. But they all arrived safely. What in one year seems foolhardy, next year becomes a perfectly reasonable thing to do. Of course there will be casualties, but these seem now to be brought down to so small a figure that even such flights as Mr. Stack's become a perfectly reasonable business proposition.

Major Andreae: I should like to know if the machine was greatly affected by the variations of climate, not only in regard to the material used in its construction, but also general performance and effect if any on the engine.

Colonel Sempill: Before asking Captain Stack to reply, I should like to ask what his petrol and oil consumption was and the time between top overhauls.

In order to help the development of private flying in this country, I would like to suggest that it would be an excellent thing if a schedule of fields suitable for landing purposes could be got out and, if possible, that such fields should be suitably marked. There are a number of fields already near to large towns and the like, the owners of which do not object to their being used as landing grounds. The trouble is that no one knows where these are. This fact was instanced very clearly the other day, as I had a telephone message from Mr. Kittel, who asked me if I could supply information as to suitable landing fields in the district of Land's End and Penzance. It would, of course, be well if these fields had 10ft. gateways so that the usual light aeroplane could be easily removed to suitable shelter if necessary.

If any of us were ever in doubt as to the truth of the old proverb that "necessity is the mother of invention," such doubts must have been completely removed by Captain Stack's vivid account of how he effected a temporary repair to his cracked cylinder head with a composition, the main basis of which appears to have been mud. There are a great many other interesting points that can be read between the lines of this Paper, and it is to be hoped that the discussion will draw out some of these from Captain Stack in his reply.

We are very glad indeed to welcome back this evening the President of this Society, Sir Sefton Brancker, after many months of absence in India and Egypt. I know I can say, without the slightest exaggeration, that if it had

not been for his untiring efforts, civil aviation and private flying in this country would unquestionably not have reached the stage that it has to-day.

REPLY

Captain STACK: Sir Sefton Brancker has asked me at a moment's notice to give an estimate of the cost of the flight. I can give you the particulars so that you can work the sum out yourselves. If your machine uses 4½ gallons of petrol per hour when it is flying at 70 m.p.h., which is the speed at which we flew, and one gallon of oil to 70 miles, and you have to pay very little more than the ordinary hotel expenses for accommodation, you can easily figure out what the trip cost. It works out at much the same as a car trip doing 20 miles to the gallon of petrol. Once possessing the machine I think you could travel and tour equally as cheaply with a light aeroplane as with a car of the same power.

With regard to supplies of petrol and oil. We had oil put down for us by Wakefield's because we preferred to use Castrol. We arranged with the British Petroleum Company to supply us with petrol and the Shell Company also supplied us in the same way. But as a matter of fact I would go on that trip to-morrow without making any arrangements for petrol and oil, because all through France you can obtain aviation spirit, B.P. and Shell. In Italy the aviation spirit is very nearly as good as you can get at home, and the oil is like our own. There are ample supplies of petrol and oil throughout Egypt, Palestine, Mesopotamia and on to India.

About getting off. We chose that particular time of the year because it was the cool weather, but in the Persian Gulf it was hot. The take-off there was longer and the climb not so fast as in England, but nothing the average pilot could not have accomplished.

Our machines were loaded 100 lbs. over their standard loading. Any machine will have a more sluggish take-off in Mesopotamia and India during the hot season.

As regards the propeller, we did take a spare each. My propeller lasted me as far as Basrah and then I had to change because one blade became half an inch out of true. Leete's lasted all the way, and when I left India he was still using the same one. My propeller which went out of track had no other trouble. The wood stood up to the varied conditions and the heat excellently.

We had very little truing to do to the machines. I had to take up a little slack in the landing and flying wires at Basrah and later at Karachi. The fittings were in excellent trim and became no slacker than one finds in doing small flights at light plane clubs.

We had the usual under-carriage of rubber in compression. My machine stood up perfectly. Leete's had a slight droop of the right under-carriage strut, but nothing serious. He still has the same under-carriage. From the time I left England to the time I left my machine at Karachi I did not once pump up my tyres. It was not necessary to put in any extra air in spite of the fact that we landed several times heavily and on aerodromes where there was camel thorn. Leete had one puncture and a little valve trouble. I think this is rather wonderful. During the day time the tyres were nearly as hard as a brick, but in the evening time they were just right.

As regards compasses. The compass we used at the time was the small 5/18 aperiodic fitted in most standard Moths. It is most satisfactory. Previously we had 5/17's, which were too sensitive, for the compass card kept twirling round at the slightest provocation. The 6/18 was excellent.

Porto Bardia is sometimes spelt Badir. It is about 30 kilometres north and west of Sollum. It is a recognised Italian landing ground, but the only accommodation is the hangar, which is a fairly large one, suitable for housing a

Capproni; it would take several Moths. There is plenty of petrol and oil there, which can be bought. In the village is a small cantonment where an officer and staff live. There it is possible to get accommodation.

When flying on a compass course, I think it is possible to keep one's course even if the compass does not read correctly. If the compass is out, for example, not pointing N. when it should and possibly deviating a few points either way, a course can be set in the following manner:—Get two objects, a factory chimney, church spire, or any two marks in a straight line parallel to your track, or a road or railway pointing in the direction of your objective at the commencement of your flight. Fly along it and take the compass reading. Or you can take a course by flying across your own aerodrome (providing you know how it is situated, *i.e.*, which are the N. and S. ends and which the E. and W.). Fly over it in the direction of your destination, take your compass reading, keep to it, and providing the wind does not alter you are bound to arrive very close to your objective.

If you have a map you can check your course as you go. Being able to recognise landmarks when you see them and checking them off on the map quickly is of the greatest utility, particularly in England where there are so many of them. If you take your map in the first place and draw a line across it to your objective, that is the track you have got to fly over. Close to that track you will find something in the nature of a landmark to fly over in your line of flight, parallel to your track. Look at your compass course or reading and keep on it. If you mark off points along that course every five or ten miles you can work out your ground speed and will know approximately when you ought to arrive at your destination. If you do not reach there at the right time, knowing your ground speed, you will either have altered your course or the wind has become stronger. I think the fault, when pilots lose their way in good visibility, is usually due to themselves and not their instruments or maps.

There was a question about whether our engines became overheated. At the beginning we were flying under conditions that were normal and I do not think my engine got too hot at all. In India it was rather hot in the middle of the day, and my engine used to give a few backfires or pre-ignite when I switched off on the ground, but I cannot say I found the engine ever too hot.

We top overhauled after 60 hours' flying. It is a point worth knowing.

As regards folding the wings, I do not think it was necessary on this trip because everywhere we had plenty of space, but where it would be an advantage is when visiting friends in this country who have only a garage to offer for aeroplane accommodation or housing.

PROCEEDINGS

TENTH MEETING, SECOND HALF, 62ND SESSION

The Tenth Meeting of the Second Half of the Sixty-Second Session of the Royal Aeronautical Society was held in the Theatre of the Royal Society of Arts, 18, John Street, Adelphi, on Thursday, April 7th, 1927, when Flight Lieutenant F. O. Soden, D.F.C., R.A.F., read a paper on "Parachutes." Colonel the Master of Sempill, Chairman of the Society, presided.

Colonel THE MASTER OF SEMPILL: Before introducing the lecturer to you this evening, although he needs no introduction, I know you would wish to record your great sympathy with the relatives of the late Mr. E. R. Calthrop, who died only a few days ago. Mr. Calthrop was intimately associated with the development of parachutes for very many years. He was the designer of the Guardian Angel, which was the best-known parachute of its day. When this lecture was arranged it was hoped that Mr. Calthrop's health would have permitted him to come, as I know he wished to hear this lecture and speak in the discussion.

A few years ago the lecturer was put in charge of the Parachute Flight of the Royal Air Force, and with this unit he toured round the country demonstrating the use of parachutes, and giving people an opportunity of trying them in practice.

I think that all of you who have read the advance proof of this paper will agree that Flight Lieutenant Soden is far too modest, and that he is the one person who is most fitted to tell us about the practical side of parachuting. He is an able follower in the footsteps of the late Air Commodore Maitland.

PARACHUTES

BY FLIGHT LIEUTENANT F. O. SODEN, R.A.F.

Before starting on this lecture I would like to point out how little I really know about parachutes. Firstly, the only parachute I have ever used is the Irvine, which is now in use throughout the Air Force. As regards other types, I have never had the opportunity of studying them really closely. I hope, therefore, I may be excused if I say the wrong thing. I would also like everyone to clearly understand that I am not one of those people who profess to like leaping about the sky in parachutes, nothing in the world scares me more, and in case there are any people here who have done one or perhaps two jumps and still think there is nothing in it, I would recommend them to try a few more. If they still continue to revel in it, all I can say is that they must have a rather distorted outlook on life.

The thought of stepping off an aeroplane with a parachute does more than "scare me stiff"; it scares me absolutely limp. From what I have seen of various types of parachutes, all designers seem to make free use of each other's designs; in fact, it would almost be impossible to try to design a parachute at the present time without incorporating certain ideas of a previous designer.

In concocting these notes I have, therefore, not hesitated in making free use of previous lecturers' ideas, and in some cases I have quoted word for word extracts from the Royal Air Force Parachute Manual.

Parachutes—Their Uses as Understood by the General Public

Until recently, parachutes have generally been, and still are, regarded as highly dangerous toys, to be used only by people who are getting bored with life. Very few people realise that they are just as essential on an aeroplane as lifebelts and lifeboats are in a ship.

Every new machine now being built for the Royal Air Force is designed to carry parachutes, and it is a punishable offence for pilot or passenger to leave the ground without his parachute. By the time a pilot is fully trained he has cost the Government several thousand pounds, and by way of insuring him the Air Ministry supplies him with a parachute which costs approximately £80.

Already, in the last eighteen months, some half a dozen lives have been saved by parachutes in this country, and this was during a period when the R.A.F. was by no means fully equipped with parachutes.

I will quote a few cases where parachutes have actually saved lives recently.

Collision.—Two "Fairy Fox" aeroplanes collided, and the crews were saved. There have also been numerous cases in other countries where lives have been saved, after similar collisions.

Controls jammed.—"Avro" controls jammed over Manston (pilot saved).

Faulty design.—A test pilot could not get his machine (a new type) out of an inverted spin. (Pilot saved.)

Engine failure over impossible country in fog, or at night.—An American trans-Continental air mail pilot was saved by resorting to his parachute, having realised that if he carried on and tried to land his machine in a snowstorm amongst the mountains, he would be killed. (Pilot saved, though injured.)

Structural failure.—An American test pilot (Lieutenant Barksdale) was saved twice. I quote this officer because he was a personal friend of mine and served with me in France.

First time—failure of tail:—

> Barksdale was testing a new machine for the purpose of studying its known instability fore and aft. At 2,000ft. he pushed the stick forward to start the oscillations, but the machine being longitudinally unstable at this speed got its nose down, gaining speed very rapidly. In attempting to pull it out of the dive the leading edge of the tail plane crumpled up, followed by the main spar. This caused the tail of the plane to flip up suddenly, the force throwing both pilot and observer out of their cockpits. Barksdale opened his parachute and escaped O.K. The observer was found dead, having failed to pull his rip cord.

Second time—wings folded back. Extract from his letter:—

> Dear ———,—I had another plane go to pieces on me on March 24th and I am still on crutches as a result. Expect to be back on duty in a week or so, however. In case you haven't heard, here is a brief description of my wreck. I was making the original flight on a two-seater plane (seats side by side) designed for air mail work. The air was very bumpy, and I was in level flight with full engine at 1,000ft. which indicated an air speed of only 115 m.p.h. The bumps caused the wing tips to begin a slight flutter, which gradually grew into enormous proportions causing the subsequent failure of the *left* upper wing, followed immediately by the left lower and then both right wings. All failed at the butt or centre section. During the gyrations I managed to loosen my belt (no passenger), was thrown clear of the plane, found my rip cord on the third fumble and parachute did the rest. I got mixed up with a wing or so going out, bumping my head a bit and pulling a few muscles here and there in my back. I also got a badly sprained and slightly fractured ankle which seems to want to stay with me, but I expect

to shake it in time. I landed backwards in a 25-mile wind on a hard-boiled hill.

Third time :—

His machine got into a spin at low altitude and would not come out. The pilot did not have time to get absolutely clear, and was killed.

Fire in the air.—French pilot and passenger saved.

In time of war, parachutes would put a tremendous amount of extra confidence into pilots, when they knew that in the event of their controls or vital parts of their machines being shot away they would have a sporting chance of getting away in a parachute.

Fire in the air, due to enemy action, was the cause of countless pilots and observers being killed in the late war. In 99 per cent. of these cases they would all have been saved if they had been equipped with the parachute which we now have. When a machine is set on fire it does not get out of control for some time. In fact, one could in almost every case see the pilot in complete control of his machine, trying to sideslip the flames away, until he could stick it no longer, and had invariably to jump out.

Observer getting away after the pilot had been killed.—There must have been a tremendous number of cases where the pilot was rendered unconscious and the observer was killed in the ensuing crash, having no means of escape. I do not mind admitting myself how careful I became for two or three days following a fight in which I had seen a particular friend of mine go down in flames.

In the case of home defence, a pilot would probably take even greater risks, knowing that he had friendly country beneath him in the event of him having to resort to his parachute. If a pilot had something to crouch behind, such as a bulky engine or a small piece of armour plate, he would not mind going right up to an enemy machine and staying there until they had shot his machine to bits, so long as he knew he had a good parachute. The fear that a pilot might be tempted to use his parachute unnecessarily, when by staying in his machine he might manage to save it, is hardly worth considering. Cases will occur, but will be very few and far between.

Few people realise to what extent parachutes were used, and can be used, in other directions, quite apart from saving life. For example :—

The Belgian Army, during the operations in the north half of the Ypres Salient in 1918, were kept supplied for several days with iron rations and small arms ammunition dropped in parachutes by the R.F.C., the ground being impassable to all kinds of transport.

On more than one occasion beleaguered garrisons out East, *i.e.,* North-West Frontier, Mesopotamia (Kut and insurrection of 1920), Egypt (riots post-war), might have been kept supplied with water, food and arms had the importance of the parachute been realised in this direction.

A case occurred in Iraq in 1921 where a pilot had to go down in a small scout so as to be able to drop tins of petrol from about 6ft. into a river in the bottom of a ravine to enable a most important wireless station to get functioning. Nobody had, of course, thought of parachutes. Many a time have machines sent out with spares to a force-landed machine crashed themselves in trying to land, whereas they might have dropped the spares by parachutes.

In 1923 one saw bags of rice and other foods being thrown out of machines from 1,000ft. to isolated troops in the same country, and in the same way as they were dropped on Kut in 1916.

I do not think that the parachutes have yet been taken seriously from this point of view. Sooner or later we must have a supply and transport side of the R.A.F. solely for this kind of work.

In the wars of the future a commander-in-chief will be dropping machine-gun teams and demolition parties behind the enemy lines in parachutes before launching an offensive. Parachute flares will reach enormous proportions.

To return to the point, that of saving lives in the air, there are various types of life-saving parachutes, classified as follows :—

Attached Types

Firstly, there is the "Attached" type, as used on balloons and airships where the parachute is hung in a bulky container on the side of the balloon basket or cabin. The observer merely jumps clear, and when he reaches the full extent of the cords the parachute is pulled out of the container and so opens. It is doubtful if this type of parachute can be improved on for this particular work.

Attached types as used on aeroplanes.—These are far more compact than those used on the lighter-than-air craft. The container is, as a rule, situated either under the fuselage or in the fairing behind the cockpit.

The pilot or observer merely has to jump clear and hope that as the parachute comes out of its container it does not foul the tail or any other part of the machine. For doing practice jumps or exhibition jumps when the machine is under control this is all very well, but it is doubtful if one could be very certain of getting away O.K. when the machine was really out of control. The pilot has not a choice of sides from which to go.

Next, we have the "Heinecke" type, as used by the Germans during the war. The pilot sat on the parachute, which, with its container, was attached to his harness. On jumping clear the pilot took with him the parachute still packed in its container. The life-line, which was of fairly lightweight cord, was attached to one end of the parachute and the other end to the machine. On the full extent of the life-line being reached, the parachute was withdrawn from its container, the life-line broke, and the parachute proceeded to function. Here we have the possibility of the life-line getting tangled or not breaking, on account of the pilot not gaining enough velocity relative to the velocity of the machine to take up all the slack in the life-line.

In spite of this, I saw just before the Armistice at least four enemy pilots save their lives with this type of parachute, and never remember having seen one fail to function. On one occasion I saw a German pilot who was forced to land on our side of the lines, leap out of his machine and make a dash for the nearest cover, quite forgetting that he was attached to the machine by the life-line. The result was that as he ran his parachute was drawn out of its container and lay stretched across the field, showing exactly where he had gone to ground. In the excitement to get down and be the first in on the silk, I landed before I noticed that we were only a few hundred yards from the enemy's front line. I just had time to discover that the parachute was made of *cotton* and not of *silk* before it was very forcibly brought home to me that I should be off.

We now come to the free type. But, before we go any further, let us take into consideration the points to be remembered when designing a parachute to meet present-day demands :—

1. It must be possible for the wearer to leave the aircraft when in any position.

2. The operating means must not be complicated or liable to foul, and must not be susceptible to damage through any ordinary conditions.

3. The parachute should, when packed in its container, be of such a size and be so disposed as to give maximum comfort to the wearer and permit him to leave the aircraft with the least difficulty or delay.

4. The parachute must open promptly and must be capable of standing the shock incurred by a heavy man falling at anything up to 300 miles an hour.

5. The parachute must be controllable to a certain degree.

6. The harness must be comfortable and very strong. It must also be adjustable to fit the largest and smallest person.

7. The strength throughout must be uniform from the harness to the top of the parachute.

8. It should be possible for the wearer to release himself easily and quickly from his harness, so as to prevent being dragged.

9. The parachute should be as simple as possible in construction, and should be easy to pack and maintain.

There are two different kinds in this country, viz., the "*Holt*" and the "*Irving.*" The latter is the one now in use in the Royal Air Force.

Apart from the fact that both the Holt and the Irving are much more compact and up to date than the "Heinicke," they are worn in much the same way, the main difference being that having jumped clear, the pilot is not connected to the machine in any way. Instead of a life-line, the pilot when clear pulls a "rip cord," which opens the container and releases a "pilot" parachute (a small umbrella on springs) which in its turn pulls out the main parachute.

The "Irving" parachute has several features in its construction which appear to be very original.

Firstly, it is a free type and is operated by the pilot when desired.

It has a "pilot" parachute which ensures the quick opening of the main parachute, no matter in what position the parachutist may be. If the parachutist is falling with his parachute directly underneath him, the pressure of the wind will press the parachute hard up against his back and in all probability remain thus until he turns over. The pilot parachute overcomes this. I had an example of this during my first jump in America. I said to myself, "God bless that pilot parachute" as it rushed past me, dragging the main parachute out after it. The cords are of silk, with the result that they are much stronger than the usual cord line or tape. Silk cord becomes untangled very easily on account of its slipperiness. The cords do not merely go from the harness to the periphery or edge of the parachute, but from the harness to the periphery and on right up across the parachute body, down the other side and back to the harness again. This has much the same effect as putting a net over a balloon. The flaps of the container or pack are opened, when released, by pieces of elastic cord. The silk body is made in sections, cut on a "bias," the idea of this being to prevent a small tear in the silk, if one should occur, from spreading too far.

It will be noticed on inspecting the parachute that the biggest tear one could get before coming up against a seam would not exceed two feet.

The harness is exceptionally strong, and the whole combination of harness cords and silk body is designed to withstand terrific strains due to opening the parachute at high speeds. This makes "delay" drops possible.

There is no quick release or shock absorber between the cords and the harness, as this has been found to be unnecessary and in any case would only tend to make the parachute more complicated.

On being delivered to the R.A.F. each parachute is thoroughly inspected, packed and dropped tested with a dummy twice before it is issued for service.

As far as practice parachute descents in the Royal Air Force are concerned, they are all voluntary. A trained Parachute Section (looked on, I'm afraid to say, rather in the same way as the Execution Squad patrolling Shanghai at the present

time) visits each aerodrome in England in turn, and sooner or later affords everyone there " who wishes " an opportunity to make a parachute descent.

It may be of interest to some of you to know that officers and men of the R.A.F. of every rank from Air-Marshal down to A.C.2 have made parachute descents within the last eighteen months, and that includes doctors, dentists, padres, accountant and store officers, staff officers, clerks, batmen, cooks and butchers, etc., etc. This rather belies the statements which have appeared in the Press headed " The Royal Ground Force."

To start with, a Bristol Fighter was used from which to carry out practice jumps, owing to the fact that the exhaust pipe made a convenient ledge to jump from. The Bristol was soon given up, as it was found that some pupils could not resist pulling the rip cord before they were well clear of the tail, with the result that there were very nearly one or two nasty accidents.

Jumping from an aeroplane in " cold blood " with no real incentive is very different from suddenly and unexpectedly finding that one must jump, and it must be remembered that the wretched pupil has probably been thinking of his jump for days before, and by the time he finds himself hanging on to the side of a machine with a couple of thousand feet of clear air under him, he is screwed up to a pretty high pitch of nervousness, and I don't think one can altogether blame him for wanting to be a bit quick on the " ring-pulling " business.

In view of this, a " Fairey Fawn " was fitted with a ladder, so that by the time the pupil found himself standing on the bottom rung he was well below the tail, and it did not really matter if he did pull the rip cord too soon. One did not, of course, tell him so. This, needless to say, was far more comforting to the pilot to know that he would have a tail left him to land with.

A great number of jumps were carried out from the Fairey Fawn, until eventually Corporal Wilson was killed at Andover. On investigation it was found that the rip cord had not been pulled, and the passenger in the back of the Fawn said that, having let go of the ladder, he appeared to lose his nerve, let go of his ring, make a grab at the ladder and miss it, with the result that he either fainted or kept on pulling a bit of harness instead of the ring. This happened to an American pilot. He had to jump in earnest and in the excitement of the moment he pulled at a buckle instead of his rip cord ring. On realising this he put his hand down and allowed it to travel up his side until he felt the ring.

The case of Corporal Wilson raises the point of how often the human element is going to fail. Some people at once say, " Why not fit an automatic opening device?" The answer to that is, that automatic devices of this nature are apt to be unreliable and complicated, and only about one per cent. of parachutists would rely on them. Apart from this case of Corporal Wilson being killed, there were several more cases of people being nearly killed through carelessness or loss of nerve. To prevent any further cases of personal failure it was decided to adopt the " pull off " method, and thus allow the pupil a little parachute air experience before letting him execute a free fall or " live " jump.

The " pull off " is carried out as follows :—

A twin-engined machine is used, and has a small platform built round the base of the rear outer bay struts. The pupil climbs into position on the ground, and the machine takes off with the pupil standing in front of the strut and looking out past the tail. In this position the wind presses him hard against the strut and he experiences no difficulty in hanging on.

When the instructor (in the nose of the machine) wishes the pupil to get ready to go, he signals to him to climb round the strut until he is facing the front; in doing this, the pupil has to hang on fairly tight. When in the proper position, he has to let go of the strut with one hand and take hold of the ring. Pupils

often blame the instructor if they finish up on a barbed wire fence, in a stream or in a wood, but in nine cases out of ten it is the fault of the pupil himself, who is so reluctant to spare a hand to get hold of the ring that he is not ready to go when told to do so.

When the instructor sees that his pupils are ready and the machine is in the correct position over the aerodrome, he signals to them to pull their rings.

Having pulled the ring, the parachute container opens, the pilot parachute is released and pulls out the main parachute, which in its turn plucks the pupil from his perch on the wing-tip. It is most amusing to watch the expressions of the various pupils—firstly, when you signal to them to let go with one hand, and secondly, when the jerk comes.

The suggestion to adopt the pull-off method at first met with a certain amount of opposition, as it was looked on as being rather too easy, but it has since been proved to have definitely saved the lives of two senior officers who otherwise would have undoubtedly been killed. This pull-off method demands no great mental effort on the part of a pupil when the time comes to make himself let go, as is the case when jumping from the fuselage of a machine. Having once pulled the ring there is no more argument. You are for it in about 1½ seconds.

I once had an international rugger player try to hang on, but luckily the strut was strong and the parachute won.

In my opinion, if there is going to be any human failure whilst doing a live drop, it is going to take place at the moment of letting go.

As soon as the parachute has opened, the parachutist must decide which way he is drifting, as on landing he must endeavour to be facing down wind, so that when he sprawls on the ground he will be able to take most of the shock on his legs and arms, instead of on the lower end of his spine and the back of his head. Besides being told how to turn his parachute, he is taught how he can stop himself from swinging; this is very necessary, because every time the parachute tilts sideways, it spills air and therefore increases the speed of descent. If, as might happen in war-time, one was being shot up by an unsporting enemy, one could deliberately spill air by pulling down the cords on one side of the parachute, thereby increasing the rate of one's fall for a few hundred feet or more if necessary.

As the earth approaches, the speed of descent appears to increase, and some people are apt to lose their heads and stiffen up. The pupil is instructed to relax his muscles slightly, and land in much the same way as after jumping off a wall. He should not try and remain standing, as this is impossible; the best thing is to roll over. One does not float gently on to the ground as some people imagine, but at a rate of approximately 17ft. per second. If one jumps in earnest and only breaks a couple of legs or arms, one has no right to grumble.

If he sees that he is going to land in water, or that he is likely to be dragged owing to a high wind, he should sit back in the harness as in a swing, and undo first the leg straps and then the chest strap, so that just before or on touching he can slip out of his harness. This obviates the necessity of having a quick release, which again only adds to complications.

Delay drop.—When a parachutist using a free type parachute purposely lets himself fall several hundred or several thousand feet before opening his parachute, it is called a "delay drop."

We in this country, as you probably know, have just lost two of the finest exponents of the long delay drop, viz., Corporal East and L.A.C. Dobbs. I am quite prepared to say that they equalled in daring anything in the way of long delay drops that has ever been done in other countries, and without advertising the fact.

Up until recently it has always been the theory that a man falling a few hundred feet from a balloon or an aeroplane would always become unconscious long before getting to the ground. This theory has, of course, now been exploded.

Corporal East, after doing over 2,000ft. dead drop before opening, has told me that he was quite *compos mentis*, although he once admitted that he was beginning to feel slightly dazed towards the end of one particularly long drop. In his recent drop of 5,000ft. when he was killed, there is, I think, no doubt that he pulled the ring a shade too late; this may possibly have been due to allowing himself to become a little too dazed before doing so.

In the interests of parachutes generally, these two men have put up the finest show possible, and apart from being extraordinarily proud of them, it is hoped that those in a position to do so will see that their dependants are not wanting. Corporal East was married only a few months previously. It will be a long time before any Air Force gets two such other men as these.

Sensation.—When dropping from a stationary or almost stationary object such as a balloon, the sensation of dropping before the parachute opens is most unpleasant, but when jumping from an aeroplane which is doing at least 65 miles per hour there is little or no sensation of that sickening drop. This is because the parachutist starts off with a horizontal speed of at least 65 miles per hour, *i.e.*, he is travelling forward at the same speed as the machine in much the same way as a bomb.

In watching a delay drop, it will be noticed that the parachutist, until his parachute opens, always appears to be directly under the machine, and as the machine is doing 65 miles per hour, so must the parachutist be doing the same forward speed, or else he would be left far behind. It will be noticed in the films that in cases of live drops (not delayed) the parachute on coming out of the container does not trail out straight above the man's body, but well out behind him. This gives one a very good idea of his horizontal speed.

Care and Maintenance

The parachute, in spite of its careful design, cannot help being cumbersome, and in fact a nuisance, but everyone has to wear it, so in view of this fact it might just as well be looked after properly as not, so that when it is wanted it can be relied upon.

A case occurred in America a few weeks ago where two machines collided; the pilot of one machine got away, as his parachute was O.K., but the other one had not got his harness on, although he was sitting on his parachute; he was killed.

The correct fitting of the harness is essential, as cases have occurred where people have been quite badly hurt owing to having their harness too loose. The general idea is that the jerk of the parachute on opening is terrific.

Provided that one's harness is properly fitted the jerk is not at all bad. One can almost describe it as the most pleasant jerk in the world, because it means that the parachute has opened.

To get the silk body of the parachute into its container it has to be folded up very tightly, and remains thus for long periods, most of which time it is being sat on. Before packing it is essential that the parachute should be thoroughly dry, and it is therefore hung in a warm dry room for at least 24 hours. The rule is that all parachutes must be unpacked, hung, dried and refolded once a month, and if at any time the parachute should get wet, it should be at once dried and repacked again.

Parachutes, as Applied to Civil Aircraft

(*a*) We now come to the question as to whether civilian pilots ought to wear parachutes or not.

Firstly, let us consider test pilots. Ninety per cent. of the machines being built in this country are for the Royal Air Force, and are fitted with special parachute seats, yet it is doubtful if more than ten per cent. of the civilian test pilots testing these machines use parachutes. There are three reasons :—

(i) The firms concerned do not take the trouble to supply them.

(ii) The firms have the parachutes, but nobody to show them how to fold or use them.

(iii) The most important reason of all—there is no order that these pilots must wear parachutes. The average test pilot does not like to suddenly appear wearing one, in case he is looked on as losing his nerve or getting windy.

I know for a fact that this is the case with several well-known test pilots in this country, because they have told me so.

When the American Air Service first started using parachutes, exactly the same thing happened, and the authorities at once did the only thing possible, which was to make the wearing of parachutes compulsory.

(*b*) As regards machines carrying more than two passengers, *i.e.*, cabin machines, it is extremely difficult to see how it will be possible to fit each passenger with a parachute. Even if one did, try and imagine the rush for the door or the number of cases of personal failure.

There is always the bright suggestion that a large parachute to take the whole cabin might be carried. This for several reasons is out of the question.

The only possible solution if parachutes are to be worn by passengers in large "cabin craft" is to have an attached type of parachute and a scheme whereby the pilot can jettison his passengers by letting the floor of the cabin drop out, or seat each passenger alongside of a window through which he can plunge.

How this idea would catch on with the air-travelling public it is not very hard to imagine.

A previous lecturer, whilst lecturing to this Society six years ago, said :—

> "The problem of getting all occupants out of multi-passenger machines is a very difficult one, but is receiving adequate attention."

Before closing I would like to emphasise one or two points :—

Firstly, if any of you ever have to use a free type of parachute, for goodness sake get absolutely clear before pulling the rip cord. On no account stand in the seat, let go the parachute, and expect to be lifted gracefully into space.

Secondly, all test pilots ought to be compelled to wear parachutes.

Thirdly, it is time an air freighter was designed fitted with parachutes for dropping supplies, etc.

Discussion

Colonel Sempill : We have listened to a remarkable lecture.

In spite of the lecturer's modesty there can be no doubt in our minds that the success that has been met with in demonstrating and inspiring confidence in parachutes is due in the main to his own efforts.

Personally, I am one of those to whom he refers as having made one descent and is thinking about making another. I have been saying so for ten years and do not feel that there is any necessity to try it again in order to find out how sensational it all is.

In considering parachutes there are certain people whom one must mention; the late Air Commodore Maitland, for instance, who did more than any other

man of our day to demonstrate the use of parachutes. Then there is Colonel Orde Lees, who has made at least 131 descents, and the late Flight Sergeant Newall, whom many of you must have seen giving demonstrations all over the country. Lately we have lost two of our finest exponents, L. A. Dobbs and Corporal East. Dobbs was, until recently at least, the only man who had made a descent from an aeroplane deliberately put in a spinning nose dive. He made two such descents in India. I should like to ask Flight Lieutenant Soden if he knows of another similar case.

Flight Lieutenant Soden has told us that the cost of the Irving parachute is £40, but I am sure he will find that the Air Ministry pays nearly double this amount. The silk alone would cost nearly the figure he mentions.

With regard to dropping mails and food, I should like to know if Flight Lieutenant Soden has heard the results of the mail-dropping tests that have been made recently at Farnborough.

With regard to opening, Flight Lieutenant Soden deplores having anything but manual control. With all respect to him, I cannot help thinking that some other automatic or semi-automatic means of opening when once perfected will be insisted on. A thin lanyard as used with the autochute, which can also be manually controlled, works very well. I would most certainly use such a device if available and secure what to me appear definite advantages.

Lord Thomson: I am very glad to be the first to thank Flight Lieutenant Soden for a lecture which I enjoyed enormously. I was very much interested in his description of his feelings and those of the ordinary person when about to make a jump.

I remember a certain experience of my own in America, when I was invited by a parachute "fan" to take a jump. I had gone round his works in the course of the morning and he showed me a parachute. When he asked me whether I would like to have a jump I replied that I had got to leave San Francisco shortly. He then said, "That is all right. You can do it to-morrow." I said, "I have got to go very early the next day." He said, "You can do it in the morning." I spent a sleepless night wondering what I should do in the morning. Thank goodness, there was a very heavy sea fog which lasted all day.

One of the most interesting among many interesting points I find the question of freighters. Flight Lieutenant Soden has given me many new ideas, and I certainly think that this is an idea to be developed.

I should like to ask the lecturer how the dummy pulls the ring. I entirely agree with the Master of Sempill and should like something that opened automatically. I think an automatic opening is the thing for all civilians.

I am sorry Flight Lieutenant Soden passed over the question of how you are to get passengers out of an aeroplane. I think it is one of the most important uses of parachute to be developed. Such a device would send up the passenger traffic on Imperial Airways by leaps and bounds.

Admiral Mark Kerr: The greatest difficulty is to overcome official lassitude with regard to parachutes. In the last year of the war, when I was at the Air Ministry, I worked hard to get them introduced. Mr. Calthrop came to see me and I got particulars from him, but though we were spending about £8,000,000 a day, it took three weeks letter-writing to be permitted to spend under £40 on a "Guardian Angel" for trial. This being satisfactory, I was told that pilots would not use it. I replied that pilots were begging me for it, and in any case they would be ordered to use it, as sailors on ships are ordered to put on their lifebelts on certain occasions. But the one great block to the parachute being issued was immovable, and we watched enemy pilots being saved by this device and our pilots being killed for want of it, with perfect equanimity, until the end of the war.

Mr. IRVIN: With reference to jumping out from an aeroplane in a tail spin, we have records of seven or eight people being saved when their machines were in this position. We have a man this moment demonstrating jumps while the machine is in a tail spin as fast as it is possible to make the plane spin. It is not everybody who can get out of a spin. He has practised it and knows just what to do.

With regard to finding the ring, I am commencing to believe that a good deal of the discussion on the difficulty of finding the ring has been from motives of publicity. Anyone who has a harness on knows where the ring is. It cannot change its position and is always there. I think a little too much is said about the possibility of not being able to find it.

I remember one case of a man who was made to wear a parachute by his employer. He did not want to wear it, but his employer insisted on it. He had never worn one before. An emergency arose and he had to jump from 1,000ft. and had no difficulty in finding the ring.

With regard to large parachutes, we have manufactured large parachutes to bring down the entire cabin, but we have given up the idea as not being practicable. In case of fire we would not want to bring the fire down, we want to leave that behind, and we have come to the conclusion also that a parachute for the whole aeroplane is not entirely feasible.

In jumping out of a passenger aeroplane there is a lot of difficulty for the successful operation of parachutes to ensure that fifteen or twenty people may escape. Getting them out of one door at one time is going to be a problem. We have moving pictures to show how six people got out of one door in twelve seconds, but this was all arranged beforehand. I think in a passenger aeroplane it will be up to the pilot to drop them out. Rather an unpleasant sensation it will be for them, but I think that is the way it will have to be worked out.

With regard to the parachutes that are now being made for the Royal Air Force, I should like to say this—that though they originated in America they are now an entirely British product, made by British labour and of British material, and made in England.

Mr. C. G. GREY: The only thing I have to say on the subject is about parachutes on air liners. Flying is dangerous enough and there is no need to rub it in by forcing every passenger to be fitted with a parachute before starting. Imagine if every passenger coming on board a cross-Channel steamboat were forced to wear a lifebelt. It would not make the Channel crossing any more popular. Yet there ought not to be any more danger in an air liner than in a steamboat.

Major MAYO: Another speaker has pointed out the difficulties involved in providing passengers with parachutes. If it is going to be necessary for passengers to carry parachutes, it seems to me that the future prospects for commercial aviation are so black that we might as well give it up now. The real position is that parachutes are quite unnecessary in commercial aviation.

Without wishing to make any boast on behalf of commercial aviation I would say that the accidents which have occurred during the last few years have not been such as to justify the provision of parachutes. It must be remembered that the risks in commercial and military aviation are quite different. In military aviation a totally different kind of flying has to be done. Acrobatics, close formation flying, and other forms of flying involving special risks have to be carried out, and there is a strong case for providing every Air Force pilot and observer with a parachute. But in commercial aviation the risks are very much less and there is no case for providing passengers with parachutes. Even in the case of military aviation, however, we should regard the parachute as being mainly useful in wartime. It is to be hoped that the additional security given by parachutes will not be used

as an excuse for relaxing efforts to reduce the very large number of accidents which occur in military aviation. It seems to me that no effort or expenditure should be spared to eliminate the causes of accidents in all branches of flying, and that reliance should not be placed on the parachute to reduce the number of fatalities.

I should like to ask the lecturer if he really considers that practice in parachuting is necessary or useful. Is it really worth while? It seems to me that when the emergency arises you will make just as good a job of it as if you had never tried before. Anyone who is going to make a mess of it through nerves will do so just as much in practice as in real emergency, so why run the risk of wasting his life in practice? Personally, the last thing in the world I should like to indulge in would be a practice jump, but I feel quite sure that I should not fail to jump clear and pull the ring in case of emergency.

It may be of interest to quote a problem which recently arose in connection with the use of parachutes. Certain single-engine machines had to be flown over very bad country, described as orchard bush, in Africa. The problem was whether it would be better in the case of engine failure to face the risk of crashing the machine on the trees or to jump from the aeroplane with a parachute and drop on to the trees. We were doubtful as to which was the better risk, so we invited Mr. Irvin to give us his advice, and the advice he unhesitatingly gave was to do without the parachute under these conditions, as the pilot would do better to risk crashing the aeroplane on the trees. However, after consultation with the pilot, we eventually came to the conclusion that Mr. Irvin's parachute was better than his advice.

Mr. J. D. NORTH: I am greatly interested in the use of parachutes generally. I should like to ask Flight Lieutenant Soden whether he considers it advisable for test pilots to make one or two live drops so as to obtain the best results from their parachutes in the event of an emergency.

With regard to sensations, it seems to me that they must be very like those experienced in high dives, and I wonder if diving would not help people to make up their minds with less difficulty when they come to try parachutes.

Mr. C. G. COLEBROOK: The point we must all bear in mind is that parachutes are intended as lifebelts. You do not usually have lifebelt practices at sea, and it seems to me that in an emergency when a parachute is required an individual faced with certain death—a state which, I believe, tends to make the mind work more clearly and with greater detachment—would be better able to manipulate the parachute correctly than he might in making a drop in the absence of any vital emergency.

Wing Commander T. R. CAVE-BROWNE-CAVE: I have been asked to express my views about parachutes for the passengers in commercial airships.

While I am not aware that any policy in this matter has yet been settled, I think it very unlikely that passengers will be allowed in any airship of ours until it has been so thoroughly tried and tested that the risk is too small to justify the rather elaborate arrangements which would be necessary to provide each passenger with a parachute and facilities for using it in emergency.

I should like to add a little to what has already been said about Dobbs. He was one of the first party of Seaman Boys who joined us at Kingsnorth in 1915. He was detailed to the Experimental Party almost at once, and has been engaged on experimental work almost continuously ever since. He invented many devices which showed great novelty and quite extraordinary ingenuity. He made them with his own hands and tested them himself usually before putting forward the proposal or asking advice. Not the safest or the most trouble-saving plan perhaps, but at any rate one which proved his enthusiasm, self-reliance and courage.

Mr. BREWER : I should like to mention an instance of the use of parachutes which has not been mentioned by the lecturer. During the war, in conducting kite-balloon experiments at Rochampton, we used to release the cable up near the balloon and drop 2,000ft. of cable to the ground. A number of people would probably have been killed by the falling cable if we had not attached a parachute to the top end to break its fall.

Flight Lieutenant POTTER : I should like to make a comment on the question of pulling the rip cord ring.

The point is really that the parachute is a life-saving apparatus, and the right moment for opening it will vary in each case with the particular type of accident and the circumstances in which it happens. It follows, therefore, that the man with a clear head and sound judgment will be saved in a greater number of varying circumstances. This type of man is also, of course, the most valuable to the Service.

One point on which I do not agree with Flight Lieutenant Soden is his remark that one does not get a sensation of sinking during the first part of the fall.

Mr. GLADWELL : Colonel Holt has had to go abroad under doctor's orders and he has asked me to contribute to the discussion on his behalf.

Flight Lieutenant Soden opened with a very brief reference to types other than the compound free parachute such as the German Heinicke and the anchored, or attached types such as the well-known Guardian Angel. He has, however, omitted to draw a distinction between a free parachute such as the French Ors, consisting of one parachute and what Colonel Holt calls the free compound parachute such as Holt's autochute and the Irving, consisting of two or more parachutes in which the smaller draws out the larger in succession.

Flight Lieutenant Soden has referred to the Holt autochute, but he has not attempted any description of it, and I will touch very briefly on the salient difference between it and the Irving, which has done fine service in this and other countries. In its principles the modern autochute is identical with the autochute built by Colonel Holt in 1919 and 1920. It is also identical in its method of functioning with the Irving parachute, and there is no reason why an airman with the same instructions should not use an autochute one day and an Irving the next.

In actual construction, however, there are some very important differences.

The Irving system consists of two parachutes, and though the autochute will equally function with two only, we always recommend the addition of a third, which we call a shock parachute 4ft. 9in. diameter which is inserted between the pilot parachute and the main. When a full-sized life parachute is drawn out by a 2ft. or 2ft. 6in. pilot parachute and there is any delay before the main inflates, it will do so with almost explosive effect and with a severe shock, which is not only a severe strain on the gear but very unpleasant for the pilot. That very gallant gentleman Leading Aircraftsman Dobbs made a number of descents under our autochutes, the first as early as 1921, and he told Colonel Holt not long ago that whereas he often got a sufficiently severe shock with service parachutes to bruise his shoulder, he never felt any shock when using an autochute.

No doubt our Air Ministry have made a number of dynamometer tests of the Irving and one of the questions I would like to ask the lecturer is, what sort of dynamometer readings they have got when the airman has fallen, say, 200 or 250 feet before the main parachute inflated. And while I am on this subject I would like to ask him what is held to be the minimum safe altitude to drop from under an Irving.

The Irving Pack takes a very hard pull to open it and release the parachutes. What about a man wounded in the hand or arm, or a man weak from loss of blood? How is he going to release his parachute by falling in mid-air?

The lecturer has not told us what percentage of the personnel at each aerodrome visited have volunteered to make practice drops under the new and easier conditions.

The lecturer has not made any reference to what Colonel Holt regards as one of the most pressing parachute problems of the day, the wearing of it on the body, and he came to the conclusion that no Air Force would remain permanently content to have its observers and gun crews hampered and their efficiency reduced by wearing a merely defensive equipment. In 1919 Colonel Holt brought out his first quick attachment pack (that is a pack that is stood in any convenient place and only coupled to the harness in case of emergency). His latest type can be picked up and coupled to the harness with one hand and in one second or less, according to where it is stowed. Colonel Holt believes that something of this sort will become universal for observers and gun crews and for the passengers and crews of airships. Colonel Holt does not believe in the feasibility of equipping civilians with parachutes on multi-passenger liners until radical alterations are made in the construction of the cabin windows and outlets.

With regard to long-distance or delayed action drops such as that in which Corporal East lost his life, it is difficult to see what military value they can have as only a very, very few specially-gifted parachutists have the nerve and judgment to make them. They are a great strain, not only on the parachute gear but on the airman's nerves and heart. The system which Colonel Holt advocates for use with his own parachutes is as follows:—A special 4ft. 9in. or 5ft. parachute is carried in a pocket in the airman's coat and a twin lifeline from it is looped round the harness belt. Before jumping, the airman withdraws the parachute and holds it in his hand, releasing it only when he is clear of the machine. This ensures a velocity of descent strictly limited and yet high enough to make it difficult for an enemy machine to shoot him. When he has fallen the required distance he deflates and draws in this parachute by means of a special device; this can be done in about 1½ seconds. He then at once releases the pack parachute in the ordinary way.

An article appeared in the Press some time ago signed by an Air Force official and explaining the methods of testing the Irving parachutes and of training the personnel. He said that a certain percentage were tested with long-distance or delayed action dummy drops, and I am sure it would be very interesting to the Society if Lieutenant Soden would explain the method of carrying out these drops.

COMMUNICATED

Major A. R. Low: The full problem of the trajectory of a parachutist with unopened parachute is complicated by the initial horizontal velocity and by uncertainty as to the mean air resistance, variable density and variable wind. A simplified approximate treatment gives with sufficient accuracy the information required by the operator. In this case it is assumed that the fall is vertical in still air of uniform density and that the terminal speed is known with sufficient accuracy from direct observation or otherwise.

The following symbols are used:—

z vertical descent from standing point.
w vertical velocity downwards.
dw/dt vertical acceleration downwards.
ρ density of air, assumed uniform.
k_d drag coefficient of pilot and unopened parachute.
S mean effective surface of pilot and unopened parachute.
m mass of pilot and unopened parachute.
g acceleration of gravity.

$w_1 = \sqrt{(mg/k_a \rho S)}$ terminal velocity.

$t_1 = w_1/g$

$z_1 = w_1^2/g$

$w/w_1 = \mathbf{w}$ $\quad t/t_1 = \mathbf{t}$ $\quad z/z_1 = \mathbf{z}$

The letters in heavier type denote non-dimensional ratios.

The downward force at any instant is the mass acceleration = gravitational mass acceleration minus head resistance.

$$m\, dw/dt = mg - k_a \rho S w^2$$

Putting

$$w_1 = mg/k_a S \qquad t_1 = w_1/g \qquad z_1 = w_1^2/g,$$

we get

$$d\mathbf{w}/d\mathbf{t} = 1 - \mathbf{w}^2$$

The solution, depending on elementary functions, may be easily verified :—

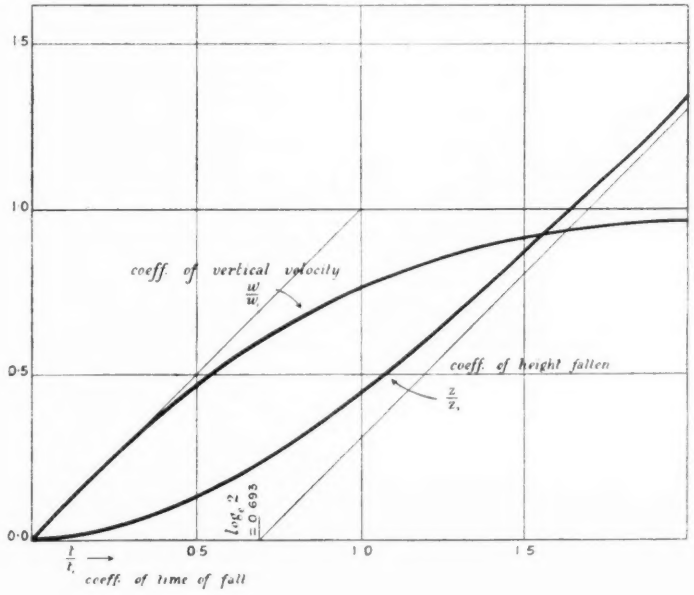
first integral $\mathbf{w} = \tanh \mathbf{t}$

second integral $\mathbf{z} = \log_e \cosh \mathbf{t}$

These are tabulated as follows :—

$\mathbf{w} = w/w_1$	$\mathbf{t} = t/t_1$	$\mathbf{z} = z/z_1$
0.0	0.000	0.000
0.1	0.100	0.005
0.2	0.203	0.020
0.3	0.310	0.047
0.4	0.424	0.086
0.5	0.549	0.143
0.6	0.693	0.223
0.7	0.867	0.337
0.8	1.10	0.518
0.9	1.47	0.830
0.95	1.83	1.164
0.964	2.00	1.33

The figure shows these relations graphically.



Using metre kilogram second units we may take $=1.25$ kg/m^3, $k_d=.075$, $S=.4$ m^2, $m=75$ kg as fairly representative values. Putting $g^n=10$ m/s^2 we get in round numbers $w_1=100$ m/s, $z_1=1000$ metres, $t_1=10$ seconds. On this scale the terminal speed is 100 m/s$=225$ m.p.h. In application a single accurate determination of the terminal velocity suffices.

With the particular numerical values assumed above 96.4 per cent. of the terminal speed is attained in 20 seconds, after which we may take the speed as equal to the terminal speed with a small error on the safe side. The first 100 metres takes $4\frac{1}{2}$ seconds, the first 500 metres 11 seconds, the first 1,000 metres $16\frac{1}{2}$ seconds, the first 1,330 metres 20 seconds. Thereafter each 100 metres takes about one second so that the release must be pulled in time for the parachute to open at not less than 100 metres above the ground if a margin of one second is desired. Below this height, fumbling for a fraction of a second may lead to disaster.

Reply

Mr. J. D. North: I do not consider it absolutely necessary for test pilots to do a practice jump, but I do think that if a pilot or observer has done a practice descent there will be less likelihood of him hesitating when faced with an emergency.

I do not consider that diving would be of any help in training for parachuting.

Mr. C. G. Colebrook: I agree with Mr. Colebrook's remarks. Experience has shown that in all cases up to date where pilots have been saved by parachute the pilots themselves have remained extraordinarily cool and collected.

Wing Commander Cave-Browne-Cave: I do not agree with Wing Commander Cave-Browne-Cave. If we are going to wait until airships are as safe as all that, it will be many years before the public are allowed in them.

Nothing short of an airship full of helium would induce me to leave the ground in one of these craft without a parachute.

Major Mayo: I agree with Major Mayo's early remarks regarding the carrying of parachutes in commercial aeroplanes. As regards practice jumps with parachutes, I do not think that it will be necessary to go on with them.

The chief idea of sending the parachute section to visit all aerodromes was to demonstrate the new parachute and explain to people how to use it, and at the same time to instil confidence.

Flight Lieutenant Potter: I agree most strongly with Flight Lieutenant Potter in his argument against leaving the pulling of the rip cord to an automatic device. As regards the sinking feeling, I have not noticed it when leaving a machine doing 80 m.p.h.

Lord Thomson: I am afraid I am not in favour of automatic opening devices.

I rather agree with Major Mayo that for the time being at any rate parachutes for civilian passengers should be dispensed with. For test dropping with dummies a lanyard is used, but we must remember that the machine in this case is flying level and is in no way out of control.

In spite of this, one has come across several cases of the lanyard fouling and breaking, or the dummy turning over, with the result that a direct pull was not possible.

With reference to getting passengers out of civil craft, I would refer his lordship to the end of my paper and my remarks on the pilot being able to jettison his passengers.

Mr. Irvin: I agree with Mr. Irvin. His remarks about leaving the fire behind and not bringing it down with him is the best argument I have heard against the very large cabin-carrying parachute.

Colonel Sempill: Since my lecture we have had the case of Flight Lieutenant Greig getting out of a fast spinning machine without any great difficulty.

I have not heard of any very serious experiments being made in the dropping of supplies by parachute during the last few years; in fact, I do not think there is much need for experiment. What is now wanted is an air freighter.

I am still all against having a lanyard or other automatic opening device for reasons stated in my lecture. If you have a clockwork or some other type of automatic opening device, it may be taken as a certainty that a novice, having set his mechanism going, will hesitate, with the result that his parachute would go off before he was ready and catch in the tail.

As regards the lanyard there is the chance, which occurs when dropping dummies, of the parachutist turning over before reaching the full extent of the lanyard and so not getting a direct pull, or the chance of the lanyard becoming entangled. Again, there is the possibility of the lanyard not breaking on account of the pilot not gaining enough velocity, relative to the velocity of the machine, to take up all the slack in the lifeline. There is also the reason given by Flight Lieutenant Potter that the correct moment for opening the parachute will vary in each case with the particular type of accident and the circumstances in which it occurs.

Mr. Gladwell: As regards the shock parachute I do not think that the extra amount of comfort in opening warrants the extra complications involved in having this third parachute. The Irving is extremely simple and easy to pack in the field.

A man saving his life in a parachute ought not to worry about damaging himself slightly in the process. The Irving will stand up to any strain that it may be called upon to take in the service.

As regards dynamometer readings I am afraid I know nothing, but I do know that the shock of opening a properly fitted Irving is not injurious.

I have dropped a dummy at 75 feet from the ground and the parachute has been fully opened before the dummy hit. The machine from which it was dropped had plenty of forward speed and was of course not out of control.

Personally, I would not use any parachute under 200 feet, and even then I would have to be in a very tight corner.

Very few normal people can truthfully say that they look forward to doing a parachute drop, and most people with whom I have had to deal said they hated the very idea of it, but they all want just to see what it is like because if "so-and-so" has done it there cannot be much in it.

A properly packed and undamaged Irving does not require a hard pull to open it.

The pull-off method was adopted in order to give the novice a little parachute air experience prior to making a proper free jump. A pull-off does give a novice a tremendous amount of extra confidence which would probably overcome that fatal hesitation which might occur when faced with an emergency had he no previous experience.

Experience has shown that prior to carrying out the first demonstration jumps on a strange aerodrome approximately 40 per cent. of pilots volunteer, and after seeing the first two or three descents the whole of the remaining 60 per cent. invariably volunteer.

On no aerodrome yet visited has it been possible to cope with the demand.

I would again like to point out that when faced with an emergency a man does not lose his nerve. Any loss of nerve which may have occurred during practice descents has been due to the fact that the pupil has been thinking of his

jump for some time before. In an emergency a man looks on his parachute as his one salvation and not as a death trap.

I have based my opinion on actual experience; my job has merely been to popularise the Irving, and knowing it to be really good I have tried to defend it against adverse criticism. I agree with Colonel Holt that a quick attachment pack for the observer is badly wanted.

Corporal East's and L.A.C. Dobbs' delay drops were not wasted efforts; they showed how strong the parachute was and to what extent a man could keep his head whilst dropping through space. No one ever intended that a habit should be made of delay drops.

I think some means of spilling air in order to increase one's rate of descent and prevent being shot at would be an excellent scheme, but the whole combination must be kept as simple as possible.

Long-distance delay drops with dummies may be carried out by means of a clockwork opening device or by means of a fuse.

The Air Ministry realised some time ago that the observer ought if possible to have a parachute which could be quickly attached when wanted.

THE ROYAL AERONAUTICAL SOCIETY AND THE INSTITUTION OF AUTOMOBILE ENGINEERS

A joint meeting was held at the Royal Society of Arts, John Street, Adelphi, London, on Tuesday, February 1st, 1927. Mr. H. Kerr Thomas was in the chair and the following paper was read:—

THE SUPERCHARGING OF AIRCRAFT AND MOTOR-VEHICLE ENGINES

BY A. H. R. FEDDEN, FELLOW.

I.—INTRODUCTION

In endeavouring to present a paper on the relative problems of supercharging aircraft and motor-car power units, the author wishes to convey at the outset that no attempt is being made to give a scientific investigation of air compression, but rather to review the present stage of supercharger development, the difficulties which have to be met by the engine designer in applying such a device to a high-speed petrol engine, and with the hope of stimulating from this review a discussion on the possible advantages to be obtained thereby.

For the purpose of this paper, supercharging an internal combustion engine may be defined as:—The filling of the cylinder during each cycle by mechanical means in the form of a pump, with a greater amount of charge than would be possible with natural aspiration.

The object of supercharging may be defined as the provision of a means whereby an aircraft or motor-vehicle engine can consume a greater quantity of mixture per cycle than would be normally possible, and from the resulting heat units set free during combustion to extract a greater output.

No attempt has been made in this paper to refer to methods of increasing mean pressure by stratifying the charge, or by the addition of extra air in the form of a supercharge, so ably dealt with by Mr. Ricardo, or by supplemented induction systems, the addition of oxygen, etc. This paper is limited to the supercharging of four-cycle petrol engines.

The artificial charging by some such means as defined above is, of course, not new, and dates back almost as far as the history of gas engines; many designs, evolved by such well known authorities as Sir Dugald Clerk, have been built both in England and on the Continent, but cover too wide a field to be touched upon in these notes, and the methods employed were not, in general, applicable to aircraft or motor-vehicle engines.

Continental patents dating back some twenty-five years show that motor-car manufacturers were thinking of the application of this device to their power units, and in the first decade of the twentieth century examples of supercharged racing motor cars were actually produced in different countries, but for various reasons they did not prevail over their rivals with naturally-aspirated engines, and were not taken very seriously, and therefore no real progress was made towards a practical solution.

As was the case with so many other engineering problems, the European War, 1914—1918, gave the first real impetus to supercharging high-speed engines by means of a pump, and serious research work was undertaken on the matter for aircraft engines, with the logical result that the accumulated knowledge was applied in the years immediately after the war to racing motor cars with remarkable results, but under conditions where cost, complication, and life of working parts were of secondary importance.

It was during 1915—1916 that experimental work was commenced on supercharging by the R.A.E., at Farnborough, and Rateau, in France; similar work

was undertaken by the General Electric Company in U.S.A. at a later date. It may be stated that the major portion of the work in these countries was devoted to the exhaust-driven turbo-compressor type.

Concurrently, experimental work was carried out in Germany and Switzerland, and gear-driven superchargers of the multi-stage type were made by Siemens, Schwade and Brown-Boveri. Experimental aircraft with supercharged engines were produced, including a German multi-engined aeroplane with a separate 120 h.p. engine to drive the supercharger, but at the time of the Armistice these installations were not sufficiently advanced to be produced in quantities.

For some years supercharging has been successfully applied to constant-pressure engines, and various examples are now existing of Diesel supercharged installations which have given excellent service.

From the above very brief résumé of the development work already carried out on supercharging, and the length of time during which this subject has been occupying the attention of internal combustion engineers, it might be fairly asked why this device has not been more widely applied to high-speed internal combustion engines for aircraft and motor vehicles; what are the main difficulties, and what are the real advantages to be obtained? The possibilities appear great, but there are also so many varying applications of the appliance that the problem has come to be regarded as one of a somewhat complex nature.

It is proposed in this paper to attempt to describe simply the main types of compressors which have already been applied to high-speed internal combustion engines, the advantages and difficulties of this form of supercharging, and the likely lines of development.

II.—Existing Types of Supercharger

In order to provide the increased quantity of fuel mixture to obtain the supercharge effect under consideration, some form of compact pump is necessary. Three main types of pumps have, so far, been employed, the centrifugal fan (driven by exhaust turbo-compressor or by gearing), the Roots type, and the eccentric-vane types. The reciprocating piston pump is not practical for aircraft and motor-vehicle engines, owing to its weight and size.

It is the opinion of the author that finality has by no means been arrived at as regards the most suitable design of pump, and undoubtedly as more thought is brought to bear on the subject, and more systematic laboratory investigation is made of the possible solutions, considerable advance will be made as regards compactness and efficiency. In fact designs, which it is not permissible to describe here, are now existent and under development in advance of anything which has been tried up to the present. Comparatively little work has yet been accomplished in real investigation of specialised designs of compressors for this purpose, and it is believed that only at the R.A.E., Farnborough, and the Langley Field Laboratories, U.S.A., is there the plant, and experienced staff existing at the present time for such research work.

It is interesting to note in passing that whereas in Europe nearly all the successful racing motor cars have employed Roots blowers, in U.S.A., almost without exception, gear-driven centrifugal fans have been employed for this purpose.

The Exhaust-Driven Turbo-Compressor

Fig. 1 shows a diagram of an exhaust-driven supercharger installation. The exhaust gases are collected in a manifold "A," which supplies the exhaust via nozzles "B" to a turbine wheel "C." This turbine wheel is directly coupled to a centrifugal compressor "D," which compresses and discharges the induction charge. In the earlier applications of this type, the exhaust gases were by-passed to atmosphere at will, involving supercharging the inlet side of the carburettor, which necessitated sealing of the float chamber and the introduction of a reducing-valve to the petrol system as the supercharge was

increased at altitude. This introduced considerable complications. In later types the compressor was introduced on the engine side of the carburettor, and the amount of supercharging was controlled by the carburettor throttle. With this

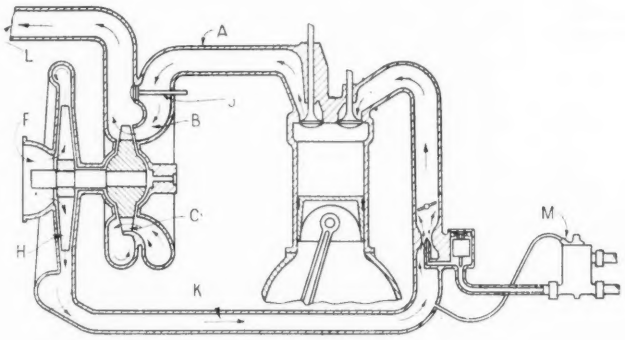


FIG. 1.

"Jupiter" exhaust turbo supercharger—blowing through carburettor.

A.—Manifold.
B.—Nozzle.
C.—Turbine wheel.
F.—Air intake.
H.—Impeller.
J.—Exhaust gas bye-pass valve (under pilot's control).
K.—Air discharge.
L.—Exhaust outlet to atmosphere.
M.—Automatic petrol pressure regulating valve.

arrangement, advantage can be taken of mechanically mixing the fuel and air; no reducing-valve is necessary on the petrol system, and the general layout and operation of the system is far more satisfactory. Fig. 2 shows a diagram of this later type. Blow-off valves shown at "D" in case of back-fire, and inter-

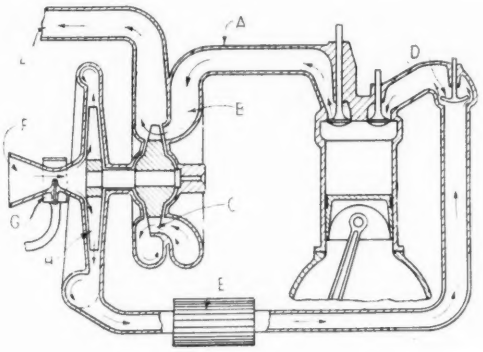


FIG. 2.

"Jupiter" exhaust turbo supercharger—sucking through carburettor.

A.—Manifold.
B.—Nozzle.
C.—Turbine wheel.
D.—Automatic blow back valve.
E.—Cooler.
F.—Air intake.
G.—Carburettor.
H.—Impeller.
L.—Exhaust outlet to atmosphere.

coolers shown at "E" to restore the induction gases to normal temperature before entering the cylinder, are absolutely necessary. This type of compressor

is not suitable for motor vehicles. At ground level the back-pressure is slightly more than that at which the compressor must deliver, namely, 4 lb. per sq. in. That is to say, an engine developing 450 b.h.p. (when naturally aspirated) should, when fitted with an exhaust-driven supercharger, deliver 400 h.p., with minus 1 lb. induction-pipe depression. With this type of compressor the boost pressure is self-adjusting within limits with increase in altitude. As the atmospheric pressure drops with increase in altitude, the pressure-difference across the turbine increases, giving greater speed to the blower, and consequent greater boost. It will thus be seen that the action of this type of supercharger is compensating. Sufficient power exists in the pressure-difference of the exhaust gases over reduced atmospheric pressure at altitude to maintain ground-level induction-pipe depression to 20,000 feet and over. The exhaust gases give an extremely smooth cushion drive without shock on sudden acceleration of the engine, and the

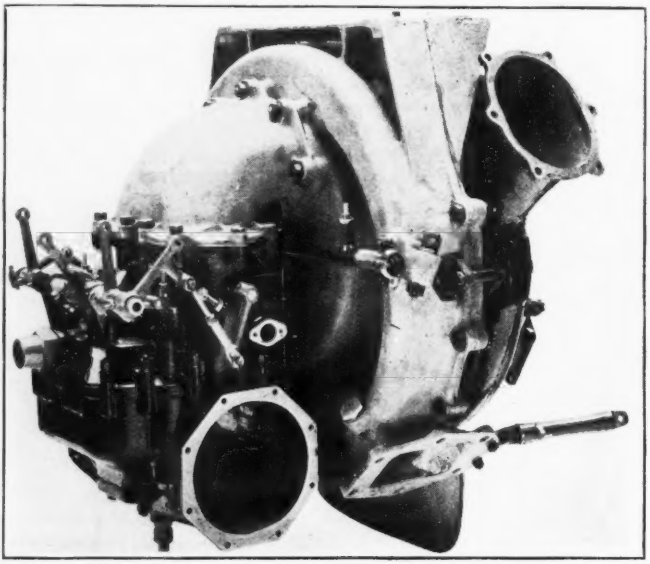


FIG. 3.

"Jupiter" engine with exhaust-driven supercharger.

steadying effect and increased smooth running of an engine fitted with an exhaust-driven turbo-compressor installation are remarkable. Ground-level depressions should be obtained at greater heights with this type of blower than with any other existing design.

The design and manufacture of the turbine wheel and casing have proved rather difficult owing to temperature differences. In order to maintain ground-level depression to 20,000 feet, and keep the compressor within reasonable limits, the turbine rotor must be run at 27,000 to 30,000 revs. per minute. The turbine wheel is revolving with exhaust gases at 650°C. to 700°C. continuously playing on it. Both these problems have been solved by careful detailed design of the casing and rotor and suitable external air cooling. The turbine rotor is made complete with blades in one piece from special high-chromium anti-scaling steel, and has proved quite satisfactory.

The maintenance of completely gas-tight exhaust joints is a difficult matter, and has proved more troublesome in practice than almost any other part of this system.

Fig. 3 shows an exhaust-driven supercharger unit applied to the Bristol "Jupiter" engine, based on designs provided by the R.A.E., Farnborough. Fig. 4 shows the turbine rotor and impeller of this unit, which, as stated above, is made of special high-chromium steel.

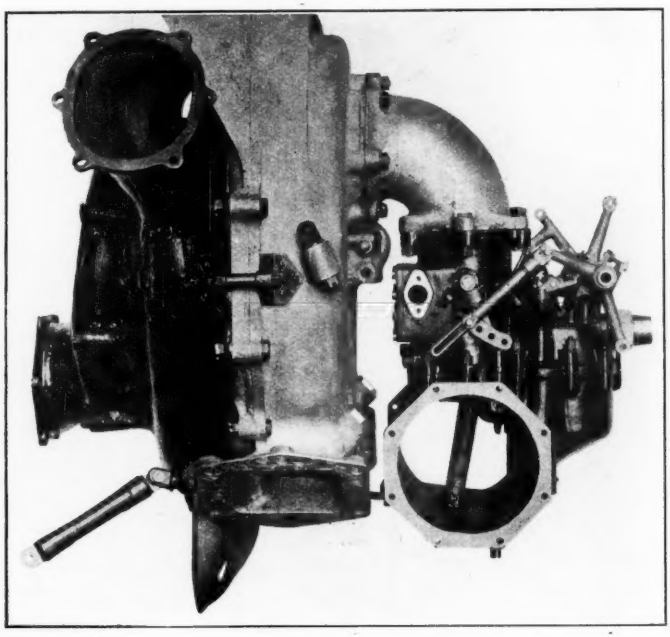


FIG. 3.
"Jupiter" engine with exhaust-driven supercharger.

The Gear-Driven Turbo-Compressor

Fig. 5 shows a diagrammatic view of a gear-driven turbo-compressor application, "A" being the spring-drive driving pinion on the crankshaft, "B" the increasing gear for the impeller, and "C" the diffuser. It will be seen from this illustration that the compressor is on the engine side of the carburettor, and in operation the whole time. Advantage can be taken of excellent mechanical mixing of fuel and air. The throttle is the only control, the carburettor conditions are normal. With this type of compressor the air at the periphery of the impeller is moving at a high velocity, but not at a great pressure. The object of the diffuser is to reduce the velocity of the air and increase the pressure.

Careful design is necessary to ensure stiffness with light moving parts in order to reduce acceleration loads, and to avoid severe stresses from crankshaft torsional vibration step-up gears between the driving shaft and the impeller of between 6 and 12 : 1 have been successfully used. The gearing naturally requires careful design and manufacture, and the teeth should be ground. It is of very great importance to ensure adequate lubrication to the bearings without getting excess oil into the induction mixture.

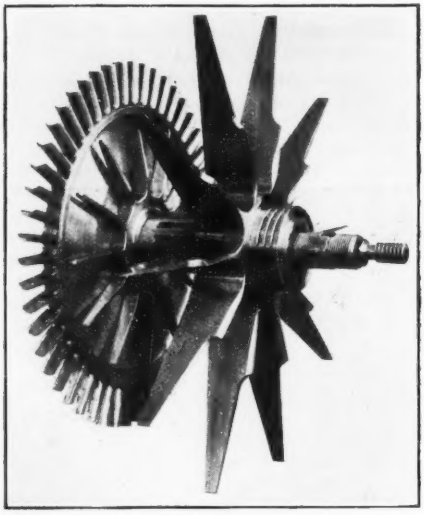


FIG. 4.
Rotor/impeller of exhaust-driven supercharger.

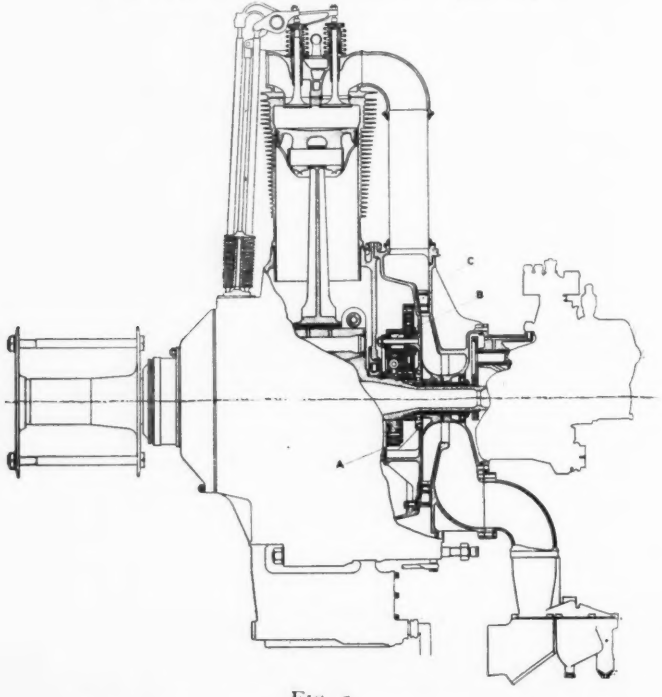


FIG. 5.
"Jupiter" engine with gear-driven blower.

A spring drive or flexible coupling between the crankshaft and blower is desirable. Light alloys of duralumin and magnesium have been successfully used for the impeller. This type of blower is applicable both to aircraft and motor vehicles.

From a theoretical point of view, however, this type of blower is probably not as attractive for aircraft as the exhaust-driven turbo-compressor, since the power required to drive the gear-driven blower at a given speed is practically constant at all altitudes. It is not possible to maintain ground-level induction-pipe depressions to the same height as with the exhaust-driven supercharger, and any effort to increase this figure would entail a considerable increase in the power loss to operate the blower and a serious reduction in the available horse-power on the ground. With this type of supercharger it is possible to dispense with inter-coolers, with moderate gear-ratios, which is certainly advantageous, and the layout makes for a very compact unit, especially in the case of the air-cooled radial. This type of blower is applicable to a motor-car engine, and can be conveniently placed on the engine side of the carburettor, thus giving the great advantage of the mechanical mixing of the fuel. The layout is, however, expensive to produce, and somewhat noisy in its present form for motor-vehicle work.

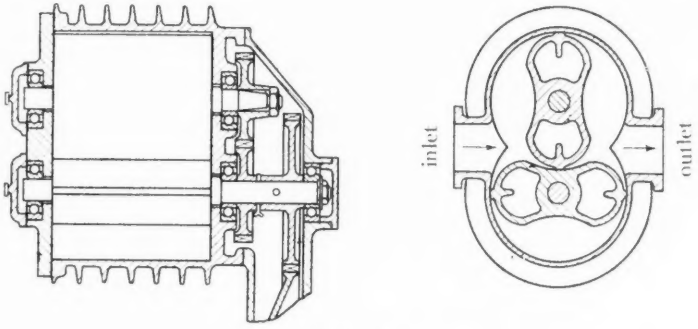


FIG. 6.
Roots supercharger.

Roots Blower

Fig. 6 shows in diagrammatic form an application of the well known commercial Roots rotating blower to a high-speed internal combustion engine. The casing consists of a light alloy casting, ribbed for strength and cooling. On the two shafts of the blower are mounted impellers of cycloidal form, rotated in opposite directions by suitable gears. A modified form of Roots blower with three-bladed impellers has also been produced with the object of cutting down leakage, but with this method the pumping space becomes small, and the delivery is therefore reduced for a similar overall size of outer casing. The impellers are made from steel or light alloy, and as the factor of safety of the impeller from bursting is a function of the strength/weight ratio of the material, light alloys, including magnesium, are quite suitable for the purpose.

This type of compressor has been very extensively used on racing cars in Europe, and has also been applied to production motor cars, although comparatively little application has been made of it to aircraft engines. It has been employed direct-driven for high-speed engines, and also with moderate-ratio increasing gears. The type is most satisfactory at high speeds, as leakage then becomes less important. It is somewhat inefficient at low speeds, and as it builds up pressure only by accumulation, the pressure in the blower at the moment

of delivery is practically atmospheric, thus the discharge rate is not uniform, and pulsations are likely to occur. A receiver or reservoir is advisable for this type of blower to damp out pulsations and to prevent phasing with the intake strokes of the motor.

The Roots blower is comparatively low in cost to produce, should be simple and reliable in operation, and very accurate balancing is not necessary. In its larger sizes, the design is rather restricted, and difficulties are likely to arise with long rotors. It would appear to become rather cumbersome and heavy in sizes suitable for aircraft engines when the necessary reservoir is taken into consideration, but the fact that a control can be introduced to by-pass excess air at low altitudes, and thus reduce the power necessary to drive the compressor, is attractive. For motor-car engines it has definite possibilities, and it is also attractive owing to its cheap construction.

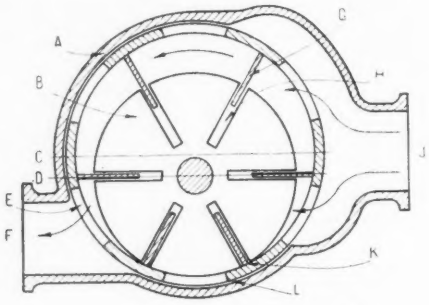


FIG. 7.

"Cozette" supercharger.

A.—Casing.
B.—Rotor.
C.—Casing centre line.
D.—Rotor centre line.
E.—Rolling drum.
F.—Outlet.
G.—Blade. Not radial to drum.
H.—Radial slots in rotor.
J.—Inlet.
K.—Rubbing contact between blade and drum.
L.—Clearance between drum and casing.

Lubrication by splash in slots.

Positive-Displacement Compressors

These include a family of vane-pump compressors, in which a series of vanes mounted eccentrically on a driving spindle rotate inside a cylinder, thereby decreasing the volume existing between two successive vanes, and thus pressure is built up.

There are two types of eccentric-vane blowers. Firstly, those in which vanes pass through fixed slots in the rotor, and the blades are free to fly out under centrifugal action till they strike a rotating drum or ring. In this category may be classed the Reavel, S.L.F. (Schweizerisch Lokomotiven Fabrik), Zoller and Cozette, Fig. 7.

In the second type, vanes pass through oscillating slots in the rotor, and blades are attached to a lavshaft which coincides with the axis of the casing. The blades, therefore, do not fly out under centrifugal action, but run with a fixed tip clearance inside the casing. The Powerplus blowers, Fig. 8, are in this category.

In the fixed-slot type of vane pump, excessive friction and wear of the blades have been experienced. To overcome this difficulty Reavel interposed a perforated rotating drum, and S.L.F. a number of floating rings, between the blade tips and the casing, thus reducing rubbing velocity and wear. Lubrication

and friction in the blade guides have proved difficult problems with the fixed-slot type.

With the oscillating-slot type, the rotating drum or rings can be dispensed with, and the blades can be balanced. Although the loading in the slots increases as the square of the revolutions in both types, it would appear that with the oscillating slot higher speeds of rotation can be obtained.

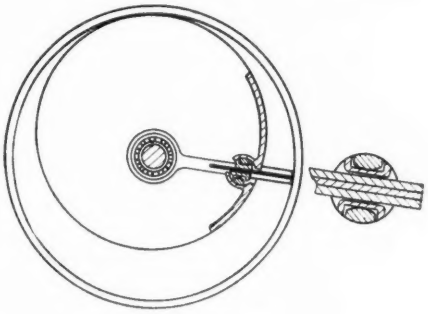


FIG. 8.

Powerplus eccentric-vane blowers.

Clearance between blade and casing.
Blade always radial to layshaft.
Forced lubrication to bearing pads.

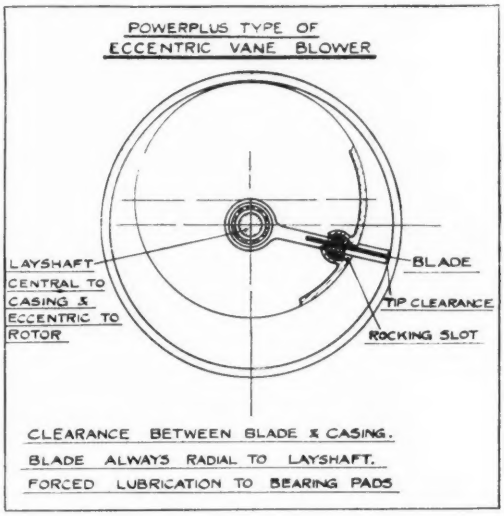


FIG. 8.

Greater freedom as regards choice of blower-casing dimensions would appear possible with the Powerplus design, which should make for compactness and lighter weight.

In single-stage form, considerable boost pressure can be obtained with the eccentric-vane type of compressor, and it has the advantages of operating

at engine speed, or with moderate increasing gears. Little is known of this type of compressor for aircraft work. Direct-driven it would appear to be somewhat heavy and bulky. With moderate gear-ratios a design of reasonable weight and

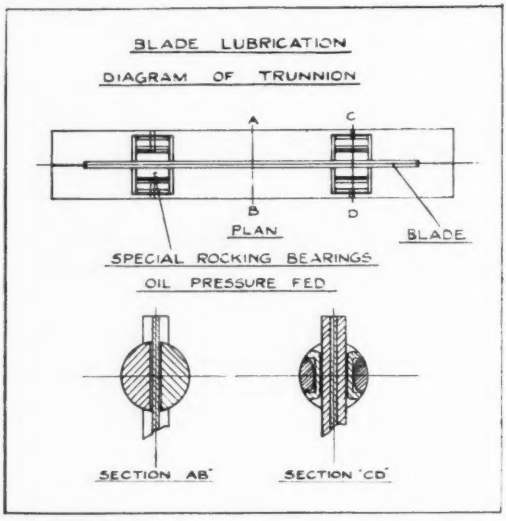


FIG. 8.

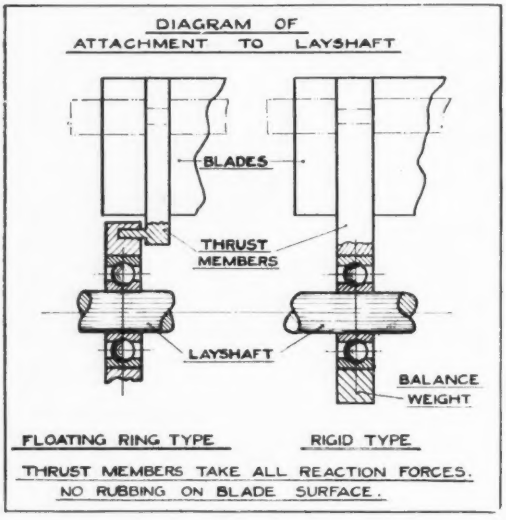


FIG. 8.

dimensions would seem feasible. The moment of inertia of the large rotor, however, is a matter for serious consideration, and might very seriously affect the synchronisation factor of the crankshaft. For motor cars this type of blower

has been employed in considerable numbers. Troubles have been experienced with lubrication, oil leakage, and rapid wear with the early fixed-slot types.

Improved designs, such as the Powerplus blower, running with a fixed tip clearance and driven direct by silent chains, offer a distinctly attractive proposition for the motor-car engine. In these sizes the overall dimensions of the compressor are reasonable, and there is no objectionable noise from the blower.

As far as the author is aware, the above brief description touches upon the most important types of compressors applied to aircraft and motor-vehicle engines. As stated previously, there are other interesting experimental compressors under review at the present time to which it is not possible to refer in this paper.

III.—Engine Problems when Supercharging

Since the object of supercharging is to obtain more power, either in the form of power recuperation for aircraft engines at altitude or an actual increase in power and acceleration for motor-vehicle engines and certain classes of aircraft engines, namely, ground-boosted type, it is obvious that this maintenance or increase of torque cannot be achieved without certain definite problems in the design of the engine arising.

Valve Timing

With a supercharged engine the valve timing approaches that of a normal slow-speed engine; the overlap can be reduced, and even eliminated. In the case of a gear-driven blower, a moderate amount of overlap is permissible, depending upon the revs. per minute and gas speeds of the engine; with an exhaust-driven turbo-blower, no overlap can be allowed on account of the comparatively high terminal exhaust pressure. The lateness of closing of the inlet valve can be reduced as, on account of the pressure available in the induction system, the volumetric efficiency is increased. Late closing would reduce the volumetric efficiency owing to the pumping back of the mixture.

Owing to the high expansion pressures of a supercharged engine, the exhaust valve need not be opened so early, in fact, if this is attempted, the loads imposed on the valve gear will be high, and the exhaust valves will become exceedingly hot. A comparatively late exhaust opening is therefore advisable.

Effect of Blowers on Crankshaft Synchronous Speed

When a blower is fitted to a radial-engine crankshaft, the system consists of two equivalent shafts carrying three flywheels, namely, the propeller, the crank system, and the blower. Such a system will have two synchronous speeds, and it is essential either to avoid both, or to place them in the region where practically no running is done, as, for example, below cruising speed. This may be done by incorporating a flexible coupling in the drive of the supercharger blower, thus reducing the stiffness of its equivalent shaft. In this connection it should be noted that the equivalent moment of inertia of the impeller is obtained by multiplying the actual moment by the square of the gear-ratio. The figure thus obtained may be quite an appreciable proportion of the propeller inertia, and will probably be considerably larger than the moment of inertia of the crank masses. The effect upon the synchronous speed of the engine cannot be predicted in general, as it depends entirely upon whether the crankshaft itself is long or flexible, or short and stiff, and upon the type of drive adopted for the blower.

In the case of line engines, the effect is even more complicated, owing to the number of harmonics present in the system. It is generally advisable in this case to make the blower serve as a torsion damper, in which case the mathematical prediction of the synchronous speeds of the system becomes difficult, in fact, almost impossible to any close degree of accuracy.

Effect of Supercharging upon Indicator Diagrams.

Supercharging increases both the mean effective pressure and the explosion pressure. Its effect, therefore, resembles that of an increased compression-ratio, but it has some important differences. In the first place, the explosion pressure for a given mean effective pressure is less in the supercharged than in the high-compression engine, and the diagram is "fatter," *i.e.*, the expansion line is higher in the supercharged diagram than in the high-compression one. The pistons, gudgeon-pins, connecting-rods (and wrist-pins in a radial engine) must be designed to stand this extra load, and the crankshaft must be designed to transmit the extra torque available.

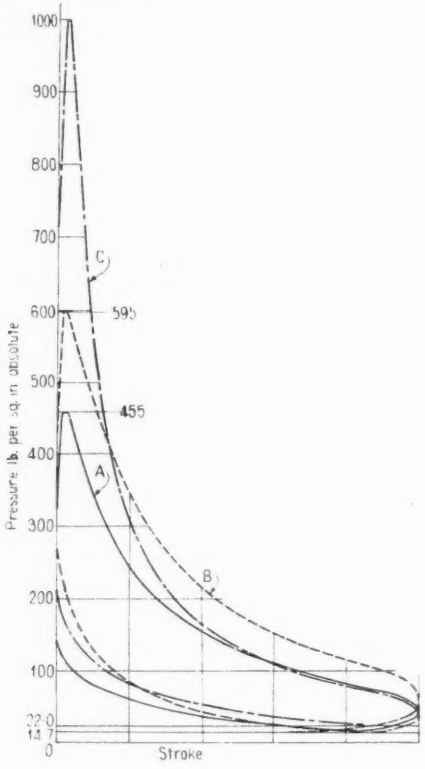


FIG. 9.

Comparative indicator diagrams.

A.—Unsupercharged, compression-ratio 5 : 1, 126lb. M.E.P.
B.—50 per cent. supercharged compression-ratio 5 : 1, 170lb. gross M.E.P. 13lb. blower M.E.P.
C.—Unsupercharged compression-ratio 11 : 1, 154 lb. gross.

In Fig. 9 indicator diagrams are given for an unsupercharged engine having a compression-ratio of 5 : 1, a 50 per cent. supercharged engine having the same compression-ratio, and an unsupercharged engine giving the same net brake mean effective pressure. From these diagrams it can be seen that the increase in maximum explosion pressure is 30 per cent. for a 50 per cent. supercharge against 125 per cent. for an equivalent increase in compression-ratio.

Cooling of Supercharged Induction Gases

The work of compression during the process of supercharging raises the temperature of the ingoing gases. In spite of the cooling effect of the fuel, the temperature of the ingoing gases increases rapidly with the degree of boost. Both at the R.A.E., Farnborough, and the High Altitude Chamber Laboratory, U.S.A., exhaustive tests have been made to determine the influence of the temperature of the ingoing gases on engine performance. With boost pressures of 5 to 6 lb. per sq. in. and upwards, and temperatures of gases exceeding 50° C., intercoolers will be found necessary.

Engine Cooling

The liberation of a greater number of heat units in the case of the ground-boosted engine, or the liberation of the same number of heat units in a rarefied atmosphere where the boiling point of water is appreciably reduced, *e.g.*, 80°C. at 20,000 feet, naturally presents another difficulty, and necessitates additional cooling and drag for the water-cooled aircraft engine. Air-cooled aircraft engines, however, score considerably in this respect in spite of the prophecies to the contrary. Actually in practice air-cooled supercharged aircraft engines have been found to function quite satisfactorily owing to their margin of cooling for full-power ground conditions, whereas with water-cooled engines it has been found necessary to increase the cooling capacity about 30 per cent. to 35 per cent. For production motor-vehicle engines, a quite reasonable increase in radiator capacity has been found efficient to deal with this problem.

Thermal Efficiency

It must be admitted that with a supercharger the thermal efficiency of the engine will be reduced: Firstly, because of the power necessary to drive the supercharger; secondly, because thermal efficiency depends upon expansion ratio, and, when supercharged, an engine is supplied with a greater charge than normal. Further, there is a limit to the detonating qualities of commercial fuels, necessitating a lower compression-ratio, thereby lowering the thermal efficiency still further. This drop in efficiency will increase in proportion to the amount of supercharge employed. This will not prove a serious drawback to the supercharger in the case of the aircraft engine in which the supercharger is used for correcting loss of power due to altitude, or in the case of the motor-car engine when used to compensate for loss of volumetric efficiency. It would also appear feasible for the moderately ground-boosted aircraft engine intended for operation at high altitudes, and where the power will commence to fall off directly the aircraft leaves the ground. Where an increase in output is required under conditions of normal efficient filling, such as is experienced with racing motor cars, the resulting effects on temperature, pressure and fuel consumption present considerable difficulties. With the latter conditions, heavy fuel consumption, greatly increased cooling difficulties, and considerably higher mean loadings must be faced. By the introduction of special dope, such as tetra-ethyl lead, some of these difficulties may be alleviated. Fig. 10 shows results obtained from an experimental aircraft engine.

At present, therefore, for commercial use we must look to the supercharger chiefly as a means to maintaining good volumetric efficiency at high piston speed.

Adverse Heat Conditions

When supercharging motor vehicles for commercial use, and employing a mild boost, adverse heat conditions will not present very serious difficulties. For aircraft engines, however, which normally work with fuller throttle openings, the conditions are somewhat different. Pistons, gudgeon-pins and connecting-rods require attention to deal with the adverse heat conditions and increased

pressures. For these engines drop-forged " Y " alloy or duralumin pistons have been found satisfactory, and when properly tooled up do not add seriously to the cost of output owing to the low percentage of scrap.

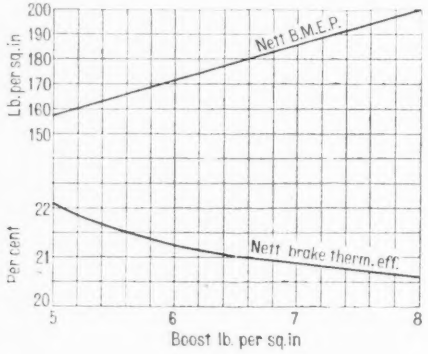


FIG. 10.

Lubrication

Reference has already been made to the lubrication problems in the blower. The correct lubrication of the blower bearings has called for some careful development work. Both at the R.A.E., Farnborough, and the Air Service Engineering Department, U.S.A., it has been found more satisfactory to feed the bearings by separate metering pumps to ensure that sufficient oil without excess is fed to the bearings. No difficulty has been found with bearings running at 25,000 to 30,000 revs. per minute as a result of this work.

Owing to the fact that with a supercharged engine the piston rings are subjected to positive pressure throughout the cycle, low oil consumptions are readily obtained even at high revs. per minute. When the throttle is shut, however, there is a tendency to oil up the plugs.

Noise

The question of noise from the operation of a supercharger has been put forward as being an insuperable difficulty to overcome. With certain types of supercharger this is certainly a serious defect, and requires tackling for motor vehicles, but for aircraft engines it is not so important; in fact, with an exhaust-driven supercharger on aircraft the engine is comparatively quiet.

Noise arises from the spur gearing usually employed, and also from air shock during the process of compression through vanes, air pockets, etc. It is believed that both these difficulties can be overcome by experimental work, and quite possibly spur gearing can be dispensed with altogether for this purpose. It is submitted that some more silent type of gear, such as the Matteucci or Burns, can be used with advantage for the driving of superchargers. The positive-displacement rotary-vane type in which the air can be compressed in the blower to the required pressure before delivery, and which can be driven at engine speed, is distinctly attractive from the point of view of elimination of noise. The latest type Powerplus vane blower, where special attention has been given to the air entry and exit, is quite quiet in operation.

Supercharged Aero Engines

The case for the supercharged engine for aircraft for high-altitude flying is a very strong one, since the density and temperature of air vary with altitude.

It is not proposed to attempt to investigate the various problems in flight at altitude from the standpoint of the aircraft, as these are somewhat complex,

and quite outside the range of the author's knowledge. It will be sufficient to mention in passing that as the resistance to the forward movement of the aircraft is, amongst other things, proportional to the specific weight of the surrounding air in which it operates, there are obviously many considerations quite outside the power developed by the motor at varying altitudes. The power output of an internal combustion engine is directly proportional to the weight of charge burnt in a given time, but as the power developed in the rarefied atmosphere decreases in direct proportion with the decrease in atmospheric density, the full-throttle ground power of any naturally-aspirated engine will be halved at approximately 18,000 feet. Quite apart, therefore, from the aerodynamic problems of flying at altitude, it will be realised readily that the maintenance or recuperation of engine power at altitude is of vital importance.

To overcome the very serious loss of power on a normal engine at altitude, without introducing a compressor, various devices have been used, such as:—

1. An oversize engine with normal compression-ratio, designed to take in an increased charge at a specified altitude to compensate for the reduced air density, the engine being throttled at ground level.
2. A high compression-ratio engine, throttled on the ground, and opened out to full throttle at a predetermined altitude.
3. A high-compression engine with bi-fuel system, using, near the ground, anti-detonating fuel such as power alcohol, and changing over to petrol at a predetermined height.
4. A variable-timing engine in which a high compression-ratio is used in conjunction with a valve gear, allowing the valve timing to be varied while the engine is running, the ideal timing being obtained at a predetermined altitude.

No. 1 is considered to be impractical, as it involves a considerable increase in weight and drag, and simply enters the aircraft designer on a vicious circle. Nos. 2, 3 and 4 have all given satisfactory service and a very considerable increase in performance at altitude. No. 3, however, entails a double system of carburation, double tanks, and also the use of a fuel of which stocks at the present time are not obtainable in all countries. Fig. 11 shows the performance at

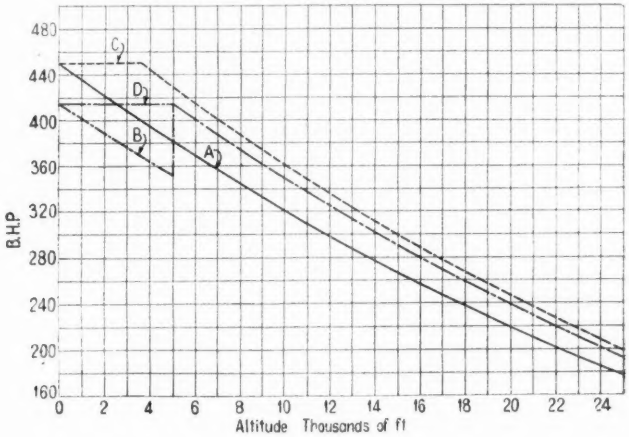


FIG. 11.

Comparative pressure at altitude, "Jupiter" engine.

A.—Standard engine 5.3 : 1.
B.—Gate throttle 6.3 : 1.
C.—Bi-fuel engine 7 : 1.
D.—V.T. engine 6.3 : 1.

altitude with these three systems as compared with a normal full-throttle ground-level-power engine, the examples being compared with a standard 450 h.p. "Jupiter" engine 5.3 : 1 compression-ratio. Types Nos. 2, 3 and 4 are considered by the author as being useful compromises only, as appreciably improved results are obtainable with a thoroughly reliable and efficient supercharger system. They have the advantages, however, of being lighter, and of not complicating the engine—matters of paramount importance for aircraft. With a properly designed compressor, power can be maintained to considerably greater altitudes, and there is also the advantage of obtaining mechanical mixing of the fuel, which will give better distribution, particularly with the low temperatures obtaining at high altitude.

All forms of compressors necessarily increase weight, and weight being a factor of the highest importance to the aircraft designer, it is important that he should be able to determine the comparative advantages of different types of supercharging, and what he will have to pay for them in extra weight.

The following tabulation has been made, taking the Bristol "Jupiter" 450 b.h.p. static radial air-cooled engine with 5.3 : 1 compression-ratio as a basis, to show what increase in power at altitude will be obtained with different types of blower, and at what sacrifice in weight this increase of power can be obtained. Fig. 12 shows the different powers at altitude with the various types of compressor.

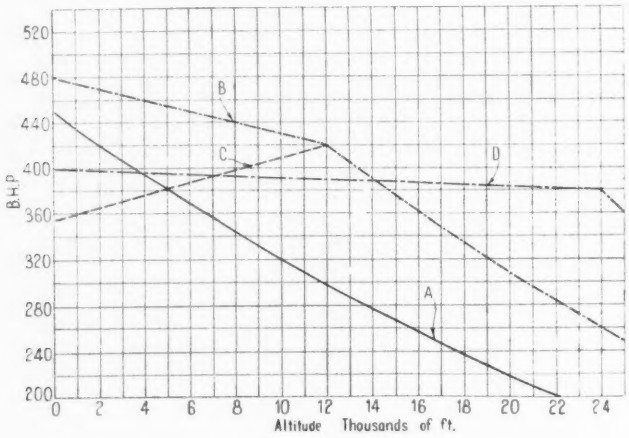


FIG. 12.

A.—Standard engine 5.3 : 1.
B.—Geared blower 5 : 1 ground-boosted.
C.—Geared blower 5.3 : 1 ground throttled.
D.—Exhaust turbo 5.3 : 1 ground throttled.

Tabulation of Bristol "Jupiter" with Weights and Different Types of Compressors

1. Standard "Jupiter" engine 5.3 : 1 compression-ratio, 450 b.h.p. full ground-level power.
   Weight, 730 lb. Fuel consumption, 0.575 pts. per b.h.p. per hour.
2. "Jupiter" engine 5 : 1 compression-ratio. Gear-driven centrifugal blower. Ground-boosted.
   Weight, 785 lb. Fuel consumption, 0.62 pts. per b.h.p. per hour.
3. "Jupiter" engine 5.3 : 1 compression-ratio. Gear-driven centrifugal blower. Throttled at ground.
   Weight, 770 lb. Fuel consumption, 0.6 pts. per b.h.p. per hour.

4. "Jupiter" engine 5.3 : 1 compression-ratio. Exhaust-driven turbo-compressor blower. Throttled at ground.
   Weight, 870 lb. Fuel consumption, 0.59 pts. per b.h.p. per hour.
5. "Jupiter" engine 5.3 : 1 compression-ratio. Powerplus eccentric-vane blower. Throttled at ground.
   Weight, 830 lb. Fuel consumption, 0.6 pts. per b.h.p. per hour.

The amount of supercharge decreases rapidly for whichever type of pump is employed, as the suction of the compressor suffers also from the reduced density. The advantages of the exhaust-driven turbo-compressor in this respect are very attractive.

Owing to the secret nature of supercharged aircraft engines, it is regretted that it has been found impossible to give illustrations of many types of engines. The author cannot refrain from expressing his regret on this matter, as he feels that, providing really confidential information is withheld, an open interchange of ideas must be of benefit to all concerned.

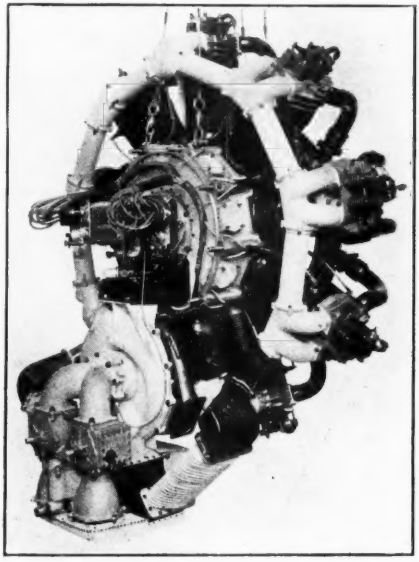


FIG. 13.
"Jupiter" engine with exhaust-driven supercharger.

Fig. 13 shows an exhaust-driven supercharger applied to the Bristol "Jupiter" from designs supplied by the Royal Aircraft Establishment, Farnborough. It is believed that this was the first British engine to fly using this system. Flight tests were first commenced in 1923, and very interesting comparative tests were made on a machine with normal engine and with supercharger fitted, the additional weight of the supercharging equipment being 140 lb. Full details of these flight tests made by the R.A.E. Experimental Staff cannot be given, but it is sufficient to say that the ceiling was increased by 10,000 feet, and the speed at the unsupercharged ceiling increased by over 10 miles per hour. No breakdown or failure has been experienced with the blower

unit, or air-cooled engine, minor troubles being confined to installation details, which have been overcome.

A considerable amount of work has also been done with the exhaust-driven turbo-compressor in America, and Fig. 14 shows an example of the application of an exhaust-driven turbo-compressor to an American water-cooled aero engine.

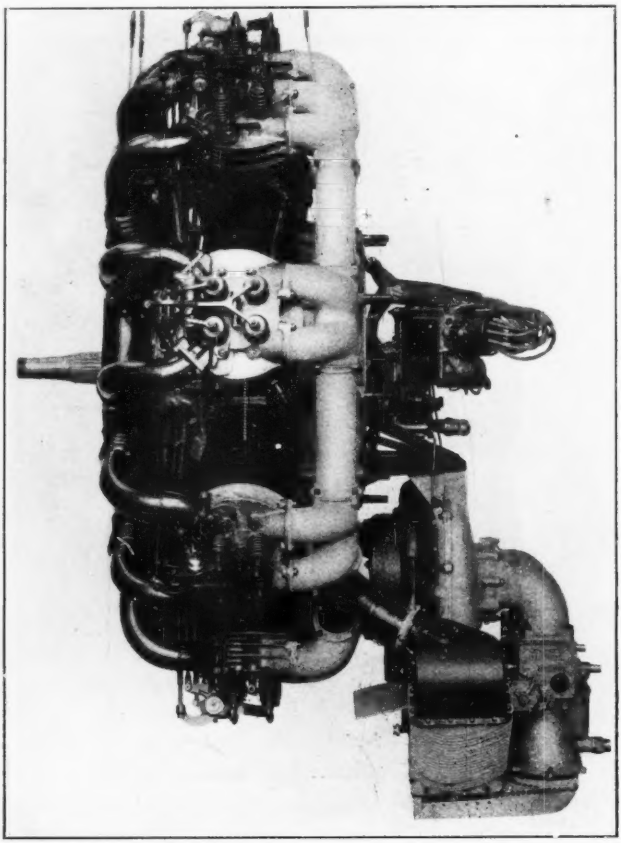


FIG. 13.
"Jupiter" engine with exhaust-driven supercharger.

Fig. 15 shows the Rateau exhaust-driven turbo-compressor fitted to a 300 h.p. Hispano engine; with this combination installed in a Gourdou monoplane, Callizo, in 1924, obtained a world's altitude record, and in 1926, with a similar compressor and a 450 h.p. Lorraine engine in a Bleriot biplane, he obtained the present world's altitude record of 40,800 feet.

Fig. 16 shows a gear-driven supercharger applied to a Curtiss aero engine.

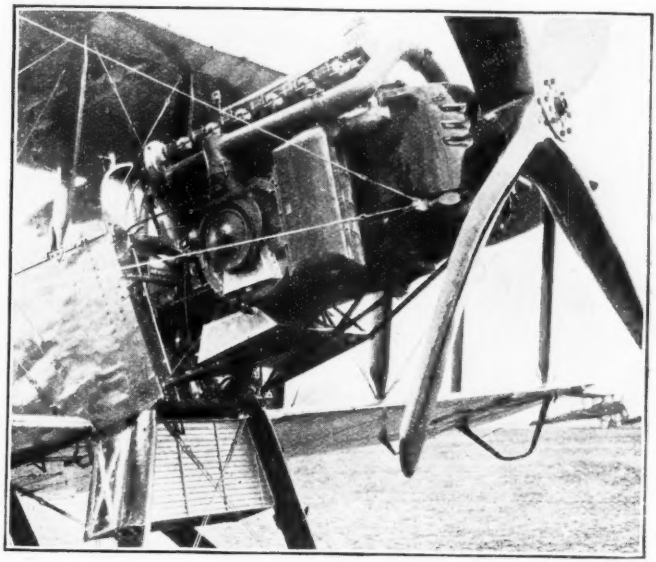


FIG. 14.

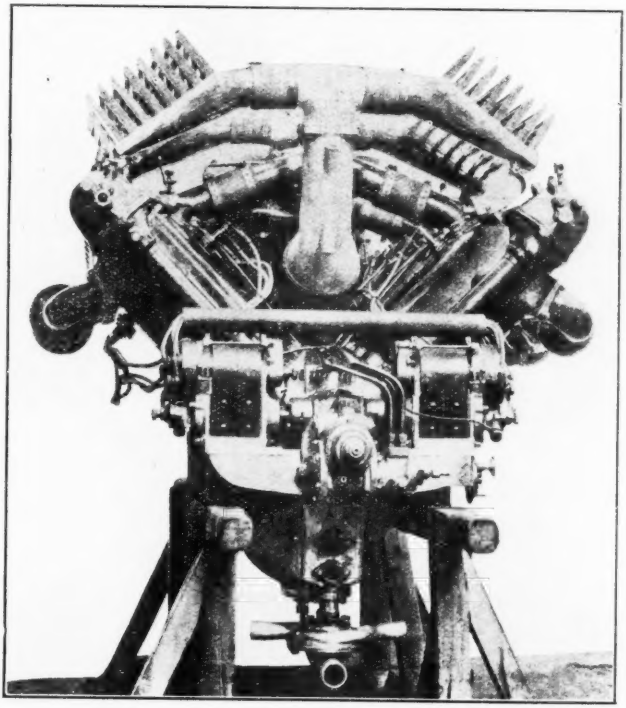


FIG. 15.
Rateau exhaust-driven supercharger.

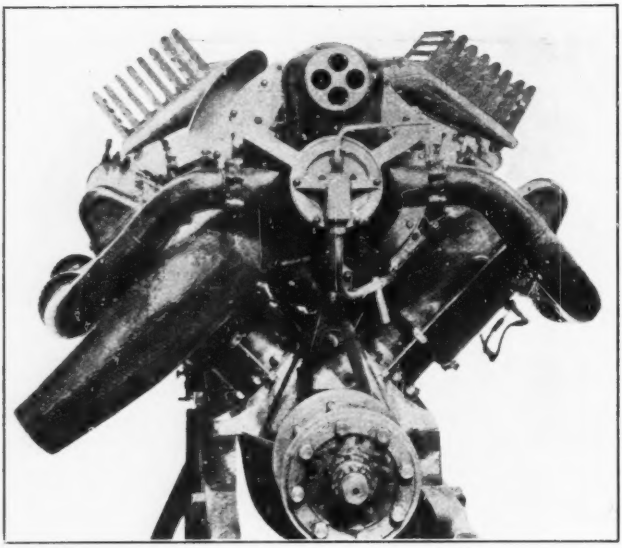


FIG. 15.
Rateau exhaust-driven supercharger on Hispano engine.

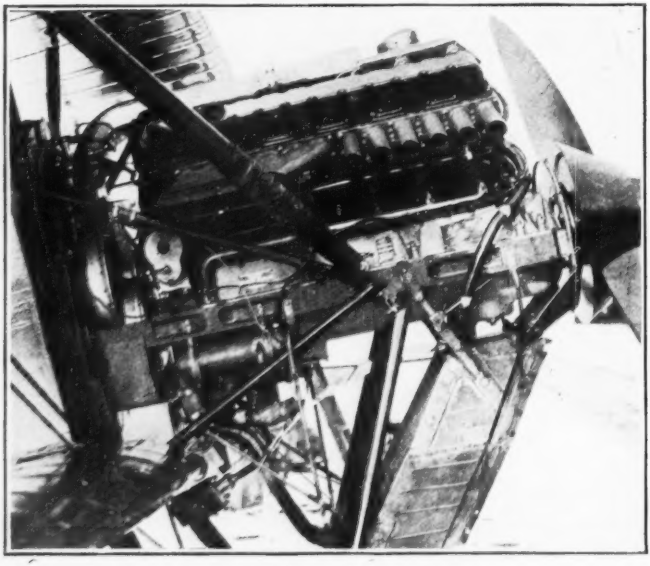


FIG. 16.
Curtiss engine with gear-driven supercharger.

Fig. 17 shows a gear-driven supercharger applied to the American air-cooled edition of the "Liberty" engine, and through the kindness of Mr. Charles Lawrance, of the Wright Aeronautical Corporation, U.S.A., Fig. 18 shows an example of the "P" type Wright air-cooled radial engine to which a gear-driven blower is applied.

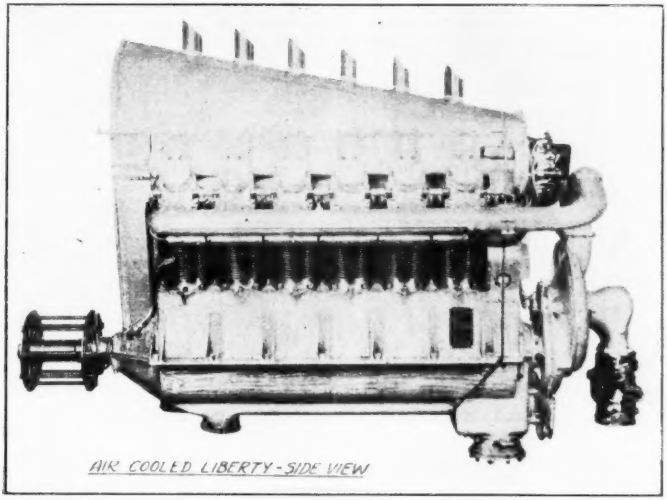


FIG. 17.

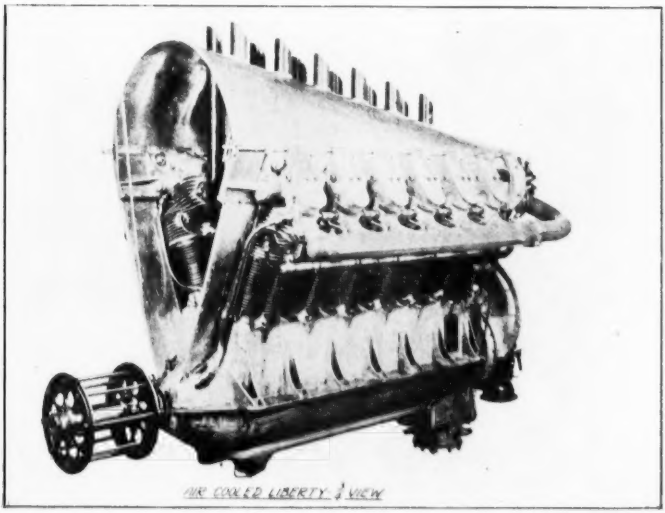


FIG. 17.

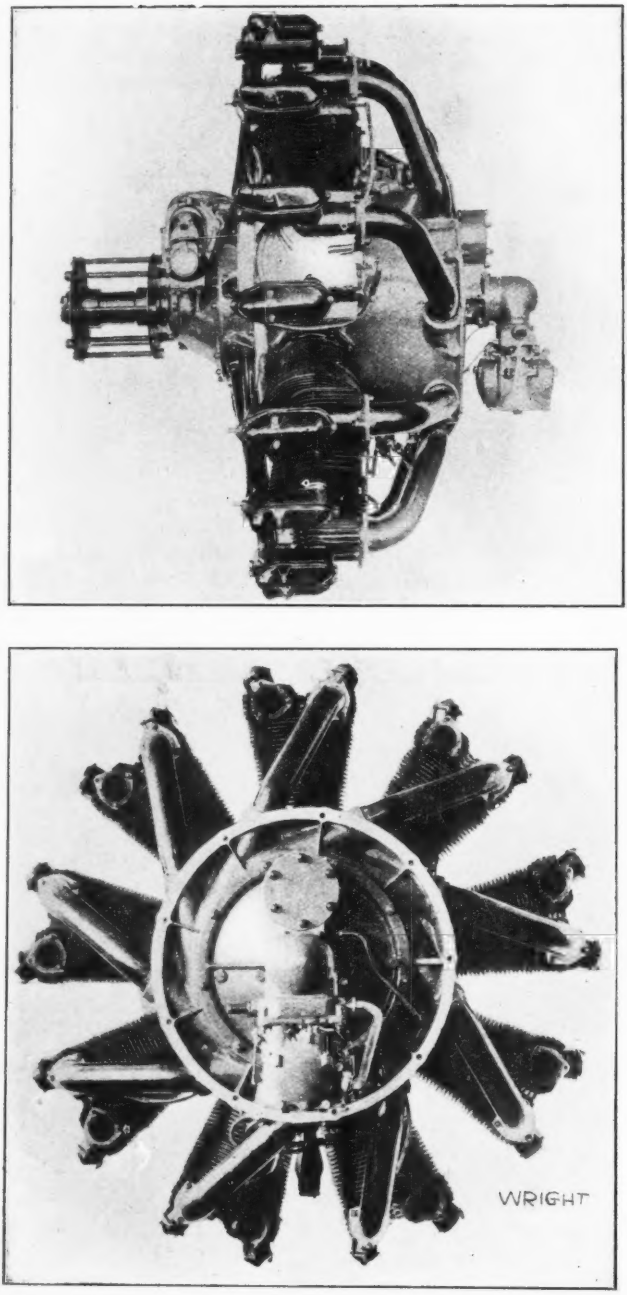


FIG. 18.
Wright engine with gear-driven supercharger.

Fig. 19 shows a scheme for the application of the Powerplus blower to the Bristol "Jupiter."

This short résumé of the work already carried out on supercharged aircraft engines should serve to indicate what great advantages will accrue. It is true that there are not a very great number of service engines in any country operating with superchargers, but this is not because the results, when properly applied, have been discouraging, but because there has been much research work to be done which was outside the scope of individual firms. The British aero-engine constructors are fortunate in having the benefit of the excellent research work carried out at the R.A.E., Farnborough, upon which, it is believed, all supercharging work on English aircraft engines has been based.

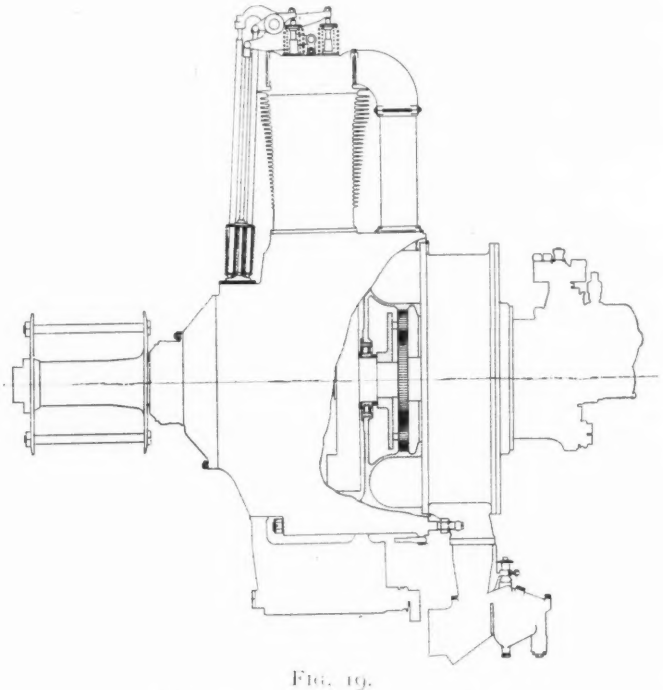


FIG. 19.

"Jupiter" engine with Powerplus blower.

The successful application of reliable supercharging aircraft units demands that the design should be considered for this one purpose from its inception, and does not permit the application of the device as an after-thought.

Supercharged Motor-Vehicle Engines

The 1926 British Olympia and French Salon, the two largest and most representative annual motor-car exhibitions in the world, are but recently over, and with one or two exceptions it may be stated that there was no great interest in the supercharger or sign of its coming into favour for passenger-car work. Reference to recent correspondence in the popular motor Press reveals the attitude of the "die-hard" type of motorist, who strongly extols the oversize type of car engine in place of a supercharger. The author is of the opinion that the case

for the oversize car engine is only a little better than that for the oversize aircraft engine.

There is a considerable school of thought which is of the opinion that we can still obtain a great deal more power per litre from the naturally-aspirated engine by increasing the compression-ratio and the revolutions per minute, and that the complication, extra expense and higher fuel consumption entailed by fitting a supercharger put it quite out of court for the engines of touring cars and commercial vehicles.

The author has been out of direct touch with motor-car design for some eleven years, and has only had the opportunity of testing and examining the detail design of one supercharged touring motor-car, but from experience gained in the study of superchargers for aircraft engines, and from a review of the development of the motor car, he is sufficiently rash to prophesy that, before very long, a change of thought in respect of the application of superchargers for motor vehicles may be expected. In putting forward the claims of supercharging for the motor-vehicle engine, it is not suggested that the application of this device is the universal panacea for all its present ills, nor that by its introduction any drastic change in the chassis, such as the elimination of the change-speed gear, might be expected; rather it is suggested that its introduction is what would be expected from a consideration of motor-car design during the last fifteen years.

What are the outstanding features in the evolution of the motor vehicle during this period? It is submitted that the salient points are, greatly increased performance, with very much more comfort, from much smaller power units. To obtain these results complication and expense have not stood in the way in the case of:—

1. The number of cylinders.
2. The application of electric lighting and starting.
3. The fitting of front-wheel brakes.

All these features, in their particular sphere, have contributed towards the performance and comfort of the present-day motor car, and without them even the moderately priced vehicle could not hope to compete. It is agreed that we have not by any means arrived at the limit of brake horse-power per litre for motor-vehicle engines, but it is submitted that a further increase will be obtained most readily by the introduction of forced feeding to the cylinders in the form of a positively-driven compressor.

The author admits that the compression-ratio of the supercharged engine may have to be reduced, as the limiting factor is the detonating characteristic of the fuel, also that as a positively-driven compressor is necessary for motor-vehicle work, there is a net loss in power and fuel to drive the supercharger. In spite of this he believes that the compressor offers the best field for exploration for increasing the output from a given engine volume.

With a supercharged engine smaller valves, cams with lower accelerations and moderate lifts can be employed, and this same mechanism can still cope with the charge at high speeds. Engineers familiar with the design of poppet valve operating gear for high-speed engines will realise what this means. The design, maintenance and noise of the poppet valve gear on high-speed engines is a very serious matter. With a supercharged engine a compromise with valve timing and overlap is not necessary.

With a supercharger operating on the engine side of the carburettor, practically perfect distribution is obtained owing to the mechanical mixing of the fuel giving better atomisation with consequent great improvement in smooth running. With this correct distribution the best carburettor and ignition setting can be obtained, with further improvement in power and fuel consumption, instead of a compromised setting, which is inevitable with the naturally-aspirated engine.

The author considers it possible to evolve a reliable, compact and effective compressor for a touring car engine, costing under £25 when fitted, operating on the delivery side of the carburettor with mild boost which will very considerably improve the power, acceleration, smooth running and quietness of the car.

Although fuel consumption has not been one of the main considerations in the past in motor-car development, because variations in temperature, climate and grades of fuel have made this impractical, nevertheless, it is believed that a supercharger can be added for a very small addition to the overall fuel consumption, because with a supercharger for a given performance a smaller engine can be used from which there will be less recourse to low gears. The better distribution also will improve fuel consumption.

For large vehicles for commercial purposes the adaptation of the supercharger is a somewhat different problem. In this sphere, also, it is believed there is hope of success. Alternatively, it might be most economical to employ a smaller engine running on practically full throttle for normal running, and use supercharging for only maximum power, which will result in a considerable saving in fuel as 75 per cent. of the running would be accomplished on an economical portion of the throttle curve, which is not the case with a normal engine, or it might be advantageous to employ a separately driven compressor to be used at will for acceleration, the avoidance of changing of gear, etc.

Whatever the final solution may be, it is believed that supercharging for commercial work will enable smaller engines to be used, giving smoother running, less wear and tear on the transmission, and the speeding up of traffic generally in congested areas due to better acceleration and less gear changing.

Power units employing compressors should be conceived for this purpose from their initial stages, and adaptations should not be made afterwards to existing designs. Such remarks may seem fatuous to the engine designer, and are only mentioned because similar adaptations have been attempted so many times in the past with unfavourable results.

As in the case of aircraft engines, illustrated examples of existing supercharged motor vehicle engines are difficult to obtain. The production supercharged motor car referred to above is the Mercédés, details of which the author was permitted to examine, and also to test the car on the road, through the courtesy of the British Mercédés Company. This car has already been so fully described in the technical Press that it is not necessary to go into any details. The six-cylinder engine is a normal modern overhead camshaft type, approximately of four litres capacity. A Roots blower with an increasing gear of approximately 3 : 1 between the crankshaft and blower spindle is operated through the medium of a disc clutch at full throttle only, by pressing the accelerator pedal beyond the normal stroke, and therefore special balance arrangements have to be taken with the carburettor as referred to previously under the section of the paper dealing with superchargers.

The supercharged Mercédés chassis conforms generally to the excellent workmanship that is associated with this make of car; the chassis is not a light one, weighing 35 cwt. The car tested was a closed saloon, the performance unsupercharged being quite ordinary with a maximum speed of 60 to 65 miles per hour, the engine being quiet, with a good slow top-gear performance. At about 17 miles per hour on top gear the supercharger could be engaged with marked results. On indirect gears with the supercharger in action the acceleration and power are remarkable. No opportunity was afforded of testing the car all out on top gear with the supercharger in operation. From the tests, an opinion was formed that no very startling improvement was obtained at low engine revolutions, but that the supercharger was employed to restore volumetric efficiency on what was intentionally when supercharged a rather mild performance. Although there is an audible whine from the blower, and the carburettor is on the delivery side, which does not seem to be the best arrangement, nevertheless the super-

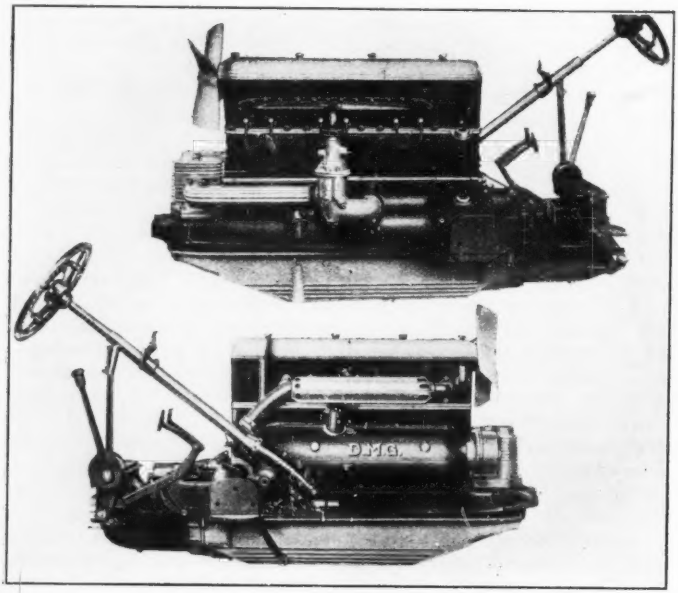


FIG. 20.
Mercédès supercharged engine.

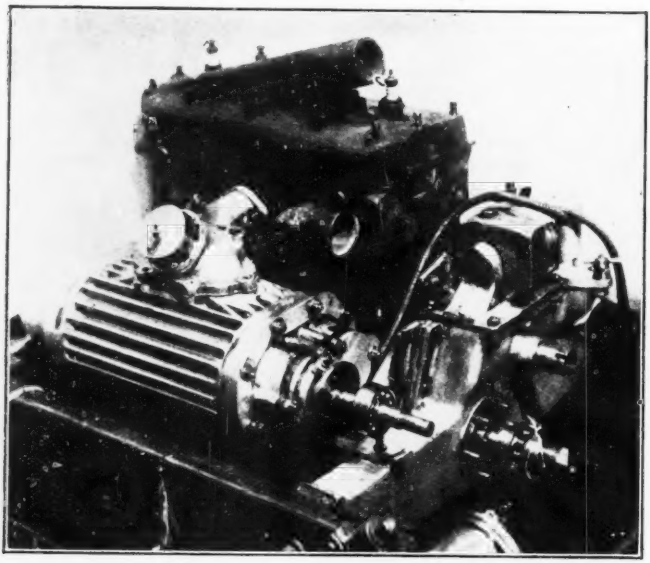


FIG. 21.
Anzani engine with Powerplus blower.

charged Mercédés is a most intriguing motor car, which, after being in production for three years, is giving excellent service and gaining ground in popularity. Fig. 20 shows the four-litre Mercédés engine with the Roots blower mounted vertically on the front of the engine.

Fig. 21 shows the British Anzani engine with Powerplus supercharger direct-driven by silent chain, the blower being on the engine side of the carburettor.

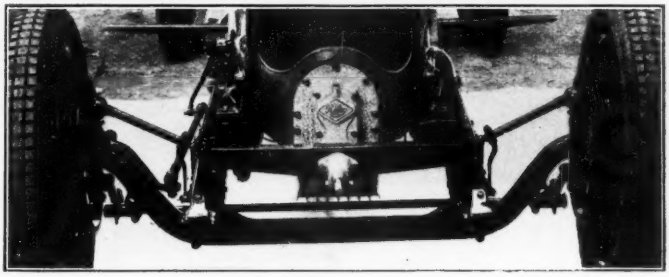


FIG. 22.
Riley engine with Powerplus supercharger.

Figs. 22 and 23 show views of the new 1927 1½-litre Riley engine with a Powerplus type of blower mounted on the front end of the crankshaft, and running at engine speed. The blower is situated between the carburettor and the engine, with a suitable blow-back valve inserted. This engine was shown in a production chassis at the 1926 Olympia Show, and is the first British car to be marketed with a supercharger as standard equipment. The author has not yet had the opportunity of testing one of the Riley cars, but has been informed on good authority that in operation the supercharger is quite silent, the maximum speed on top gear increased 13 miles per hour, some 22 per cent., and the acceleration very much improved as compared with the unsupercharged engine; the fuel consumption over extended tests worked out at 20 miles per gallon.

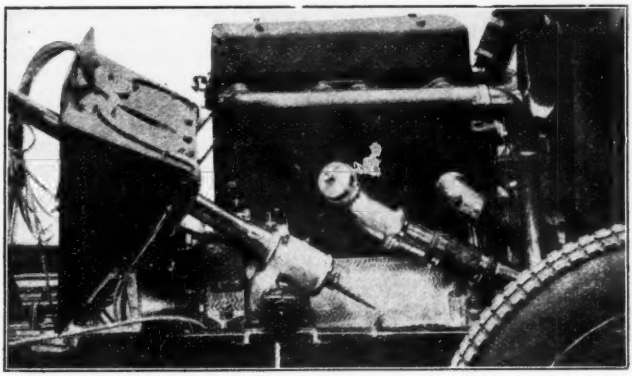


FIG. 23.
Riley engine with Powerplus supercharger.

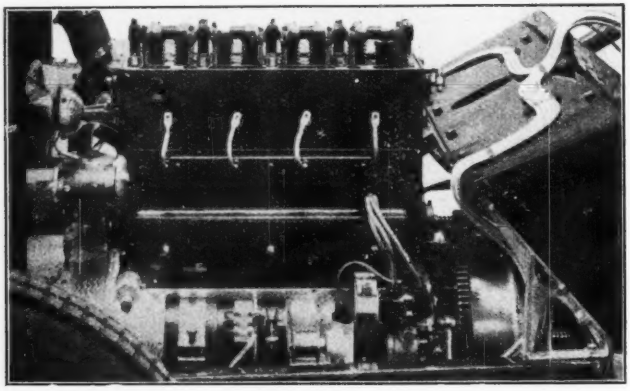


FIG. 23.
Riley engine with Powerplus supercharger.

CONCLUSIONS

In the foregoing notes it has only been possible to outline in an extremely sketchy and insufficient way the very interesting subject of supercharging aircraft and motor-car engines, and the author has especially refrained from attempting to deal with any of the various problems from a really technical standpoint, as it would be impossible to do so in any one paper. Several of the problems justify a paper to themselves.

As regards aircraft engines, it is hoped that the author has convinced the members of the necessity and advantages of supercharging for all aircraft purposes, and that within the next few years practically all classes of military aircraft engines will be supercharged as a matter of course. It is submitted that by the standardisation of supercharger engines of military aircraft:—

1. It will be possible to obtain a better performance on scouts with a ground-boosted gear-driven blower engine of considerably smaller capacity than the naturally-aspirated engine used at present, with a consequent gain in the all-round efficiency of the machine.
2. That for the larger general purpose machine supercharged engines throttled on the ground and opened out to full power at some predetermined altitude will provide greatly increased performance over any type of existing or oversize engine.
3. That for long-distance bombing machines operating at high altitudes, and when fuel consumption over long distances is of the utmost importance, there is an important field for the exhaust-driven turbo-compressor.

The introduction of the supercharger for aircraft has certainly further proved the value of the air-cooled engine, because it has been found that supercharging can be applied to this type of engine without the necessity of additional cooling, a feature which is not inherent in water-cooled engines, for which extra radiator surface is required. The exhaust and gear-driven centrifugal fan type blowers have proved especially applicable to the air-cooled engine.

As the art of supercharging is advanced, this mechanism will be applied as a standard to commercial aircraft, with a consequent all-round increase in efficiency and reduction in fuel consumption.

Most probably the supercharger will not be used continuously, but will be employed for a mild ground boost to obtain maximum power to take off, and

the engine will then be used as a naturally-aspirated one on an economical position of the throttle curve.

With the advent of supercharging the improvement in efficiency in constant pressure Diesel engines by the addition of surplus air opens out a new field for the development of this type of engine for commercial aircraft, with the great advantages of the elimination of fire risk and much reduced cost of fuel.

The advantages to be obtained from supercharging motor-car engines may not appear so urgent or obvious. If, however, the trend of motor-car development is towards greater power, with consequent increased performance and flexibility from a given volume, rather than any radical change in the power unit or gearing, then it is believed the main difficulties in the development of the supercharger will soon be eliminated.

Unfortunately the motor-car industry has not the assistance of a central investigation laboratory grappling with the basic principles of supercharging which the aircraft engine industry has in the Royal Aircraft Establishment, Farnborough. There are certain problems relating to the supercharging of motor vehicles which must be settled, the investigation of which is a very heavy burden for one firm to undertake.

The subject of supercharging two-stroke engines has been especially avoided, because this is a field quite by itself; the moment the two-cycle engine is considered from the standpoint of supercharging, the whole problem, which previously appeared rather hopeless, becomes a very interesting one.

The author wishes to thank sincerely all those who have been kind enough to come forward and supply data and photographs of supercharger development work.

Discussion

Mr. J. E. Ellor, in opening the discussion, said: Considering the naturally-aspirated engine, there remains very little to be added to our store of knowledge regarding its limitations, power developed and economy. On the other hand, in the case of the supercharged engine, the knowledge acquired of the practical application is by no means complete. In fact, I believe internal combustion engineers are only just beginning to take an active interest in supercharging and what supercharging really means. The points upon which I disagree with the author concern fundamentals. I do not agree that the economy is going to be impaired by the introduction of supercharging, and I think the possibilities are that, as research and development proceed, we may expect a better economy with supercharged engines as compared with naturally-aspirated engines. In support of this contention I should like to mention one or two of the characteristics of the supercharged engine. (1) Power developed by the supercharged engine increases in a greater proportion than the ratio of charge pressure. (2) The limiting factor to the degree of supercharge which may be applied to an engine is the physical property of materials and not the thermodynamics of the cycle. The next three items I am going to mention really concern my point with regard to economy. (3) The heat given up to the cylinder walls when an engine is supercharged is by no means proportional to the increased density of the burning gases. From that it might be gathered that if the power of the engine is doubled, the heat loss to the cylinder walls is not necessarily increased by 100 per cent. Actually it is something less than 50 per cent. Therefore, if the heat loss to the cylinder walls is not doubled, something must be gained from this source in efficiency compared with the naturally-aspirated engine. (4) The mechanical losses expressed as a percentage of the power developed are considerably reduced. In other words, if the mean effective pressure of an engine running at a certain speed is doubled, the mechanical losses increase very little indeed. If a naturally-aspirated engine has a 90 per cent. efficiency, a supercharged engine would have 95 per cent.

efficiency, a saving of five per cent., thus increasing the economy of the supercharged engine. (5) Another rather important point is that carburation and distribution are almost perfect with the supercharged engine. I am afraid that is not the case in a lot of naturally-aspirated engines, especially motor-car engines.

The last three points are assets to the efficiency of a supercharged engine. Against efficiency there is the power required to drive the compressor when the units are driven from the engine. I do not include exhaust-driven compressors. Blower units in use at the moment appear to have a common maximum over-all efficiency relative to adiabatic compression. The efficiency figure varies with the speed and size of the units, the range being from 60 to 66 per cent. The compression efficiency, of course, has a higher value. We shall no doubt have units at some future date of 80 per cent. efficiency or more for engine-driven types, which again will tend to increase economy. Against economy has been mentioned in the paper the necessity for the reduction of cylinder compression-ratio in order to allow the process of combustion to take place within the range of detonation. This is only true provided that the expansion- and compression-ratios remain the same, and even then it may be partially offset by the permissible later opening of the exhaust valve. The author stated that the efficiency largely depends on the compression-ratio, but it only does so provided that the expansion-ratio and compression-ratio remain the some. Actually, it depends upon the expansion-ratio. If high expansion-ratio is adopted and a smaller compression-ratio can be arranged for, then I do not see why the efficiency should fall.

The complex law, if one exists, controlling detonation appears to be very elusive, but certain facts influencing its limitations are known to be common to both the supercharged engine and the naturally-aspirated engine. Two of the important factors are temperature and pressure at the end of compression. It is therefore true to say that temperature and pressure before compression are important factors influencing the limits of detonation. Bearing this in mind and assuming a standard fuel to be used, the choice of compression-ratio for the naturally-aspirated engine is very limited for ground-level conditions. High compression-ratios in the naturally-aspirated engine may be used to give increased power and economy at altitude, but such engines will suffer both in power and economy when throttled on the ground in relation to the engine having a normal compression-ratio. It should also be noted that in the case of naturally-aspirated engines operating at altitude, the carburation and distribution are bad and the percentage mechanical losses increase. As a result of this the economy will suffer. I am speaking now of a naturally-aspirated engine; although certain results may be given on the test bed, it does not follow that similar results from an economy point of view are obtained in the air. The petrol consumption per horse-power increases very considerably as the altitude increases.

With regard to the mixture coolers applied to supercharged engines, operating as they do with a two-stage compression, by taking advantage of cooling the mixture after the first stage, the limits of detonation are raised, and an increased quantity of charge may be pumped into the cylinders, producing increased power. This has a bearing on the compression-ratios, and viewing the merits of a cooler from a practical point of view, if the ratio of added weight per unit of net power gained is less than the weight power ratio of the engine, its inclusion is worth while. The author has made reference to the use of anti-detonating fuels. It may, however, be taken for granted that such special fuels have similar effects on both systems, with a slight advantage to the supercharger case. Reviewing the situation from a practical aspect, it is well known that cylinder stresses in the normal engine are very low indeed, the thickness of metal being chosen from the constructional point of view. It may be taken that a normal cylinder may have its mean effective pressure doubled without exceeding the factor of safety. The heat stresses increase very little in the cylinder, but the exhaust valves come in contact with a greater quantity of heat. Valves and plugs are therefore subjected

to rather severe treatment, but in view of the recent developments in metallurgy there is every reason to be hopeful that a supply of suitable material will be available to cope with the demands as development proceeds.

There is one point of great importance, namely, that the supercharged engine must be designed around the principle instead of attempting to accommodate the principle to a design intended for a naturally-aspirated engine. That point, I think, is very important indeed; to try and boost an existing engine, already designed to have a minimum safety margin, is rather asking too much. If, for instance, a crankshaft designed for a certain stress has 50 per cent. more power put through it, long life cannot be expected from this component. The same reasoning also applies to the connecting rods and pistons. It also follows that in order to obtain the best results the designer should have before him a fuller knowledge of the characteristic changes imposed upon an internal combustion engine when supercharged. I agree with the author's remarks that organised research into the possibilities of supercharging would amply repay the internal combustion engineers of this country. As pointed out in the paper, the success of the two-stroke engine depends largely upon the efficient application of supercharging, whilst there appears to be a tremendous field for the supercharged compression-ignition engine. In the latter case detonation does not harass its application, and, due to the nature of combustion, large quantities of excess air may be supplied to aid efficiency as well as reducing the temperature cycle. For many reasons, therefore, I submit that until further investigation has fully developed the supercharged engine, it will not be possible to assign a figure of merit which may be directly comparable with the naturally-aspirated engine.

Mr. F. A. S. Acres: The author admits that the fuel efficiency of a supercharged engine will be less than that of a naturally-aspirated engine, so that from the motor-car point of view, the supercharger is definitely a step backwards, though it has justified its existence as far as aeroplane engines are concerned. Superchargers will tend to still higher revolutions, because it is only with higher revolutions that the small motor-car engine with a supercharger can maintain its volumetric efficiency. Colonel Fell, in a paper* regarding racing-car engines, quoted certain figures of brake mean effective pressure which were only four or five per cent. more than the figures I obtained on an engine in 1914. I obtained then, from a three-litre engine, a brake mean effective pressure of 137 lbs. at 3,400 revolutions per minute, whilst Colonel Fell's figures were 142 lbs. at 4,200 revolutions. The supercharger is frankly a rating dodger. It is going to make motoring very much more uncomfortable, and, according to the author, it is going to put up our fuel consumption, though Mr. Ellor has put the case that it is possible and even probable that we shall get a better fuel consumption.

Mr. A. F. Evans: This paper shows very definitely the need of the Diesel engine, not only for automobile work, but also for flying. Apparently, the supercharger is necessary for flying work, because of the low pressure at high altitudes, but there seem to be a great many difficulties in the way of obtaining the results aimed at with the ordinary petrol engine, such as detonation and firing back into the mixture, which are removed by the use of the Diesel engine. I will go further and say that the supercharging of the Diesel engine would make the two-stroke engine for flying purposes quite possible.

There has been a little progress made in France with the two-stroke petrol engine, in which a form of supercharging is used, inasmuch as the pressure of the scavenge is somewhat high, and by using a double-piston cylinder with the two pistons slightly out of phase it has been possible to reach 130 lbs. brake mean effective pressure at 4,500 revolutions per minute. This seems high for a two-stroke engine, but with the Diesel engine there are no restrictions at all as to the fuel proportions, and misfiring only occurs to a very small extent, and the power

* See *Proc. I.A.E.*, Vol. XIX., p. 477.

need not be proportional to the amount of air pumped. The air can be set to any desired quantity, and the power developed by the engine can be regulated by the amount of fuel injected.

Mr. J. HARRISON: The high-efficiency engine is already noisy, and the addition of a supercharger will tend to make it even more noisy and uncomfortable. I regard the supercharger as having been evolved purely as a rating dodger, and if competition rules were altered so that cars were classed upon any other basis than that of the volume swept by the pistons, it would die a natural death. I cannot, for instance, see it being used in a race where fuel-consumption limit is imposed. The fuel consumption of supercharged small cars in long-distance races on the track seems to be utterly disproportionate to their performance. Nor is the engine smaller or lighter than the medium-speed engine of similar power. It is merely a large engine with small cylinders. It probably costs ten times as much to build as a touring-car engine and shows not a single advantage. The supercharger will simply accentuate the faults of the high-output engine. It will make it still faster and still more inefficient.

Examination of the two-stroke engine evolved in France led me to think that the Roots blower was merely a substitute for the crankcase compression and could not fairly be classed as a supercharger.

Mr. C. B. DICKSEE: Unquestionably, when applied to correct a loss of volumetric efficiency, supercharging gives very fine results for a relatively small expenditure of power and without any loss of thermal efficiency beyond that entailed by the power absorbed in driving the supercharger. When, however, we try to use it to obtain an increase in power at ground level and under conditions which allow of a high volumetric efficiency with natural aspiration, we get a quite different result.

TABLE I.

The Effect of Supercharging as Determined by the Air Standard.

Total compression-ratio	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Supercharge ratio, Rs	1.0	1.2	1.5	2.0	2.4	3.0	4.0	6.0
Expansion-ratio, Re ..	6.0	5.0	4.0	3.0	2.5	2.0	1.5	1.0
Efficiency, $E = 1 - 1/Re^{0.4}$	0.512	0.475	0.426	0.355	0.306	0.241	0.150	0.000
Output, E × Rs ...	0.512	0.570	0.640	0.710	0.735	0.724	0.600	0.000
Output ratio	1.00	1.11	1.25	1.38	1.43	1.41	1.17	0.00

Before talking generalities, we should go back to the Air Standard and see just what it is possible to get. The proper basis of comparison is an engine using the highest compression-ratio which present-day fuels will allow, that is about 6.0 : 1. The supercharged engine is really an engine having two-stage compression and an expansion-ratio equal to the compression-ratio of the second stage of compression. Thus, with a fixed total compression, as the supercharge ratio increases, the expansion-ratio must decrease, and with it the efficiency. The power of an engine is a function of the efficiency multiplied by the weight of charge supplied, so that, at any degree of supercharge, the power developed will be proportional to the product of the supercharge ratio and the efficiency on the Air Standard for the corresponding expansion-ratio. Table I. shows the results of taking a total compression-ratio of 6.0 : 1 and a number of different supercharge ratios. From this we see that the efficiency of the non-supercharged engine is 0.512, and the power output may be expressed as unity. For a supercharge ratio of 1.2 the expansion-ratio drops to 5.0 : 1 and the efficiency to 0.475. The power output, however, is 1.11 as compared with the non-supercharged engine. Examining the series, we find that the power reaches a maximum with a

supercharge ratio of 2.4 and an expansion-ratio of 2.5. At this point, however, the efficiency is only 0.306, although the power has risen to 1.43. If supercharging is pushed still further, the power falls off owing to the rapid drop in efficiency. The ultimate is reached when the supercharge ratio is 6 : 1 and the expansion-ratio 1 : 1 when the efficiency and power are both at zero. Thus, for a total compression-ratio of 6 : 1 we have a maximum increase of 43 per cent. in power output from the working cylinder. From this, however, the power required for compression in the supercharger will have to be deducted. This is not returned during expansion, as the compression takes place in a different cylinder or the blower.

To obtain some idea as to what this deduction means, I made a complete analysis of the cycle, making the usual allowances for heat loss, change of specific heat, etc., and taking the value of γ for expansion as 1.25. The more interesting results of this analysis are shown in Table II. Taking the point of maximum output as determined by the Air Standard, we see that after deducting for the work done on compression in the supercharger we have only a ten per cent. increase in power over the non-supercharged engine. We also find that the point of maximum output has moved to where the supercharge ratio is 2 and the expansion-ratio 3. Here the Air Standard efficiency is 0.355, the net efficiency is 19.5 per cent. as against 34.6 per cent., and the output 1.175, or an increase of 17.5 per cent.—a rather small gain for a pretty large sacrifice in efficiency. This takes into account the work done in compressing the gas only, and makes no allowance for mechanical losses in the supercharger, which are probably considerable. The only figures which I have of the power actually required are those for a gear-driven centrifugal supercharger for the Liberty engine. The total power absorbed to give ground output at 20,000ft. was 57 h.p.

TABLE II.

The Effect of Supercharging upon a Practical Cycle of Operations.

Total compression-ratio	6.0	6.0	6.0	6.0	6.0	6.0
Supercharge ratio	1.0	1.2	1.5	2.0	2.4	3.0
Expansion-ratio	6.0	5.0	4.0	3.0	2.5	2.0
Supercharge press, lb. per sq. in., abs.	14.7	18.6	24.9	36.2	45.9	61.4
Temperature at end of expansion, °K.	1,710	1,780	1,880	2,016	2,102	2,210
Indicated efficiency of power cylinder per cent.	34.6	32.0	28.6	23.4	20.0	15.6
Efficiency deducting power lost in supercharger per cent.	34.6	31.4	26.9	19.5	15.8	9.0
Output ratio of power cylinder ...	1.00	1.11	1.24	1.35	1.39	1.35
Output ratio, net output	1.00	1.09	1.17	1.175	1.10	0.85
Power lost in supercharger /Output from power cylinder, per cent. ...	0.00	2.2	6.0	13.4	21.0	36.6

An important point is the temperature of the exhaust gases. Under the conditions I have outlined the temperature at the end of expansion goes up with the supercharge ratio, as shown in Table II., and at the point of maximum output is 300°C. higher than for the non-supercharged engine. This means an increase in exhaust-valve temperature, with a corresponding increase in trouble.

The problem of supercharging is a very interesting one, and under certain circumstances is exceedingly useful and valuable. There are, however, many misconceptions as to what can and what cannot be done, and the paper and discussion should bring out the limitations of the system.

Colonel W. A. Bristow: With regard to the advantages of supercharging from the practical point of view as applied to automobiles and from the point of view of aircraft, I think the discussion is completely out of date. The amount of

heat lost to the cylinder walls is immaterial, but with a supercharged engine the speed of an aircraft at 20,000ft. altitude can be increased by something like 100 per cent., and for that reason alone the case for the supercharged engine is unassailable, even if the fuel consumption is greater than in the case of the naturally-aspirated engine. The remarks which have been made with regard to the application of superchargers to motor-car engines have been based on the assumption that the supercharger was to be used at all times. With an engine doing 85 per cent. of its running at well below normal power, no one wants a seven-litre engine for running a few thousand miles in town in a year, and if a three-litre engine will serve for most of the requirements, why run about with a very much larger engine of much greater weight, more costly on tyres and petrol, and at present more costly for taxation purposes? What is the objection to having a two- or three-litre engine with a supercharger that can be clutched in at places where rapid acceleration is required and on hills? In that way the ordinary car performance could be improved enormously by the application of the supercharger, which, according to the author, can be obtained at a small cost, and which, at the rating at which it is used, will probably have a reasonably long life.

A supercharger for occasional use should not be regarded as an accessory, but as an integral part of the equipment incorporated in lieu of extra volume in the engine, which is only required on occasions, which is costly in maintenance and running expense, and which causes the engine to be normally run at far below its maximum thermal efficiency.

Major E. G. Beaumont: I suggest that for the road vehicle the supercharger is wanted at low speeds. We know, for instance, that for heavy passenger-vehicle services one of the first requirements for dense traffic work is rapid acceleration, and it is there that a supercharger of the intermittent type, as used on the Mercédés engine, might help to solve the problem. What set me thinking of this was the explanation by the author of the three diagrams in Fig. 11. The curve of the engine with the supercharger shows a high mean effective pressure, a lower maximum temperature and no greater heat stress in the cylinder, and so far as the heat effects upon valves and stress on parts are concerned, there would not appear to be any disadvantage for short-period use, and it might, therefore, be serviceable for heavy passenger vehicle duty. Furthermore, some advantages may accrue from using this apparently retrograde cycle. It is recognised that at the high-temperature end or combustion part of the cycle big losses occur with the ordinary cycle, but by supercharging, these losses would be minimised, and there may be some improvements in fuel-mixture composition and distribution for car engines, all of which tend to compensate for what at first glance would be considered the unnecessary expense, complication and weight of the supercharger for road-vehicle work.

Mr. E. T. Tapp: We have heard the suggestion that a supercharger should be used in connection with light high-speed car engines. To carry this suggestion to a positive conclusion it seems necessary to build a car with an extremely small engine and to fit a supercharger in order to see what it can do. To a certain extent, indirect experiments have been carried out in the reverse direction in connection with commercial vehicles, *i.e.*, by increasing the vehicle and load instead of reducing the engine size.

One instance I have in mind is that of a certain engine fitted to a lorry built to carry four or five tons at a fuel consumption of six or seven miles per gallon. Practically the same engine is now used in a six-wheeler and carries a twelve-ton load. It does the same journeys with a consumption of about 4½ to 5 miles per gallon, giving approximately 100 ton-miles to the gallon as against a previous 60 or 70, and with a larger proportion of paying load.

Generally speaking, the machine functions well, but has the disadvantage that when conditions are exceptionally difficult it is slightly underpowered. Under

such circumstances I think a supercharger might prove of value. I would therefore like to suggest that there is a field of use for the supercharger in connection with heavy vehicles and moderate-speed engines.

Mr. H. KERR THOMAS: The author states that a supercharger could be fitted to a touring-car engine for £25. I do not dispute that figure, but I would like to point out that nowadays the purchaser of a car of a reasonable size expects to get the whole engine for that price. My own experience is that designers now have to go over the chassis from end to end and find pieces costing 1¾d. which they can throw overboard without the purchaser bringing him to book. There is certainly no margin on any ordinary car, except perhaps in the larger luxury cars, for an accessory, however advantageous, which is going to cost £25. I think that must necessarily be a stumbling block to the use of supercharging on road vehicles for a considerable time, although possibly for the very heavy commercial vehicle the advantages would outweigh the initial cost.

Mr. FEDDEN, in replying to the discussion, said: I have followed Mr. Ellor's remarks with particular interest, in view of his specialisation on, and lengthy experience with, supercharging and allied problems, and the fact that a large proportion of my firm's supercharging experience has been obtained in collaboration with him and the Royal Aircraft Establishment.

Mr. Ellor, even allowing for the enthusiasm and optimism of the specialist, makes out a very strong theoretical case for the supercharger, far stronger than I have dared to do, bearing in mind its present state of development, and that in engineering, theory has usually to compromise with practice. For example, Mr. Ellor assumes the use of a mixture cooler, whereas for purely practical reasons this item is seldom used, and still more rarely satisfactory.

I am glad to see that he stresses the importance of the designer having a fuller knowledge of the consequences to the engine when supercharging.

Mr. Acres raises the question of the brake mean effective pressures obtainable with supercharging; apart from my own figures obtained on aero engines, I think that the results obtained on Sunbeam car engines, as given by Captain Irving in the Wolverhampton discussion, are pretty conclusive of the big advance made over the 1914 results quoted.

As to the supercharging engine being a rating dodger, I fail to see that this is any disadvantage, provided that its inclusion gives an all-round beneficial result. I do not agree that the application of a supercharger for motor-car work is a step backwards. Even in its present stage of development, if we accede to the argument that the object of the designer of the motor-car engine is to obtain maximum performances from the smallest capacity engines, I believe the fuel consumption in the present very undeveloped state of the art would be very slightly increased, but as Mr. Ellor has pointed out, this may be actually decreased as more is known about the supercharger.

Mr. Harrison's condemnation of the supercharger is so sweeping and final that I feel there is hardly anything more to be said. It would appear, however, that he has based his views on supercharging on the particular case of the racing car, which I expressly stated was the extreme case which I did not wish to deal with in this paper. As superchargers are at present, I agree that in a racing event where a fuel consumption limit is imposed, it is quite possible they might not be employed. I emphatically consider, however, that such a rating would be far less advantageous for the development of the motor-car, and in fact would bring forth a crop of more undesirable features than the supercharger, as was the actual case in the motor-car races so organised in France a few years ago. It is the duty of the successful designer to dodge the particular rating in vogue.

I can assure Mr. Harrison that the picture of the supercharged standardised motor-vehicle engine is not nearly as black as he paints it, and that there are people in all countries of the world giving the matter their most serious attention in spite of his wholehearted refutation of the problem.

The case for the supercharged aero engine is already proved, and I believe that the same will apply to the motor-car engine. It will not cost appreciably more than the present touring-car engines, and will be smoother and quieter for a given speed.

I agree with Mr. Evans that the supercharger opens up an entirely new and hopeful field for the Diesel engine for aircraft purposes.

Mr. Dicksee's views from a theoretical point of view are very interesting, but unfortunately 60 per cent. of his supercharge figures deal with cases which could never be considered in practice, and this, in conjunction with the fact that none of the straight engines under consideration operate for any length of time under running conditions at anywhere near the total compression-ratio of 5.0 : 1, makes his tables somewhat misleading.

Under these conditions the actual compression-ratio is seldom anywhere near the theoretical due to throttling in the case of the car engine, and the fall in atmospheric density with altitude in the case of the aero engine. Under these modified conditions the supercharged engine is working far nearer to the desired conditions than is the unsupercharged engine. High volumetric efficiency with natural aspiration, except at low revolution speeds, is, I am afraid, almost impossible to accomplish, except by the introduction of engine characteristics which I believe are more undesirable than a supercharger.

Finally it should not be forgotten that there are occasions when extra power is urgently required, even at the price of temporary increase in fuel consumption. Such temporary increase in fuel consumption, even with the present stage of development of the supercharger, need not be serious, and the ability to make use of the increase in power may actually reduce the total fuel consumption over a given period.

I quite agree with Colonel Bristow's remarks regarding the use of a large motor-car engine, and believe the supercharger will be of considerable help in reducing engine size without losing overall performances.

I would like to point out to Mr. Kerr Thomas that the figure of £25 quoted as the cost of a supercharger is based on the supercharger unit as an accessory or proprietary article, but I am sure that a suitable type, turned out on a production basis by the actual car manufacturer, could be made at an appreciably lower cost, apart from any saving which would be effected by the use of a smaller engine.

I believe that once the supercharger can be proved successful in the high and medium price cars it will be simply a question of development before we find it employed on the popular models.

I would remind Mr. Kerr Thomas, with his wide experience of production methods, that there are all kinds of fittings, such as electrical equipment, front-wheel brakes, radiator shutters, etc., which are now standard practice on the cheapest motor-cars, but which were considered non-essential freaks when first tested. If the supercharger is capable of what I believe it is, I feel sure it will be included in the standard equipment of cheap cars, in the same way as other improvements.

COMMUNICATED

Colonel THE MASTER OF SEMPILL wrote: The Royal Aeronautical Society values highly these joint meetings with the Institution of Automobile Engineers. The two bodies have so much in common, and an exchange of ideas must do a lot of good to both.

The early efforts at the supercharging of motor-car engines referred to by the author were of undoubted value. It is particularly unfortunate that secrecy plays such an important rôle in these days, and prevents a really complete consideration of this, and many other, important problems. It is obvious that there is a considerable way to go yet, and as a temporary measure it would appear that the decision not to continue with the bi-fuel system was a serious mistake.

In my opinion a high-compression engine with bi-fuel system offers the best means, without the use of a compressor, of in a measure overcoming the serious difficulty of loss of power at altitude.

I should like to ask the author if he does not consider the use of a variable-pitch airscrew to be essential for supercharged engines.

The author is one of the most outstanding authorities on the design of aero engines in this or any other country, and has done valuable pioneer work in the field of air-cooling, with the result that we can find to-day British air-cooled engines under construction in the Occident and the Orient.

Major F. STRICKLAND wrote: The advantages and disadvantages of supercharging will vary very much according to the use to which the engine is put. In racing under a cylinder-capacity classification, " volumetric efficiency " in itself is the essential object, weight and petrol consumption being of secondary importance. Aero engines for great heights are again a very special case.

For most other purposes, however, such as vehicle and marine work, weight, fuel consumption and cost of upkeep are the main considerations, combined with silence and freedom from vibration. Volumetric efficiency is only of value so far as it contributes to these. To put the matter simply, it would be quite easy to treble the volumetric efficiency of a locomotive, but it would be heavier and more costly to run. I doubt very much whether any one would wish to pay a higher fare or go slower simply to know that the locomotive had a higher " volumetric efficiency."

So what we want to know is what are the relative weights and petrol consumptions of two engines, one supercharged, the other not, of the same horse-power and constructed sufficiently substantially to have the same cost of upkeep.

Unfortunately, we have very little information on this point in the paper. Weights and petrol consumptions of a Jupiter engine are given in the paper, supercharged and unsupercharged, and in each case both weight and petrol consumption are increased by supercharging. The horse-powers are not stated, but I should presume that the engine could not be run supercharged at materially more than the normal horse-power without increasing the load on the bearings, and in this case they would have to be made more substantial to get the same durability.

If we take an ordinary well designed non-supercharged engine for a motor vehicle or boat and substitute one that is supercharged, we must reduce the weight of the engine by the amount of the supercharger to get the same total weight. The engine must of course give the same power, so the bearings, shafts, etc., must be up to transmitting this power. I should have thought that under these circumstances there was very little margin indeed for a reduction in total weight, and unless there is a perceptible reduction either in weight or petrol consumption, I do not see any advantage, for the supercharger will be a certain extra cost and must sooner or later require repair.

I should therefore imagine that for all ordinary purposes the non-supercharged engine would remain in general use unless some very much simpler form of supercharging comes in than those described—the arrangement developed by Sir Dugald Clerk and Mr. Ricardo, for instance. Another plan which seems to me possible is to have a jet of steam, air, or exhaust gas at high pressure in the inlet pipe to induce a faster flow. Such an arrangement would only require a very small pump, or if exhaust gas were used it could be taken direct from the cylinder.

Mr. A. E. L. CHORLTON wrote: When Sir Dugald Clerk took out his first supercharging patent in 1902, his object was rather to reduce flame temperature than to boost the power. In the modern application, when the air pump is driven direct or through gears from the engine itself, I have found that the power required to drive the supercharger sometimes amounts to one half of the extra power made possible by the added air. Can the author give, if possible in the

form of a table, the values of power to drive and the net increased output for centrifugal type and rotary type superchargers?

I suggest that, despite what the author has said, some consideration should be given to the piston type, bearing in mind that the original Clerk supercharger was of that type and in this method use was made of the front side of the piston, and this plan was also adopted by Mr. Ricardo.

I suggest a tandem form of engine construction, in which the space under the top piston could be used as the supercharging pump alternatively for either cylinder.

However, I think that the exhaust-driven type is really the one that will hold the field in the future, and suggest that more attention should be concentrated on it in this country; we are too dependent on the Farnborough type and the Rateau.

A simple form is the Lorenzen, a German design, in which the exhaust-driven rotor wheel and the centrifugal air impeller are combined in one. Moreover, an alternative method by which a supercharger is applied should be developed. The port method has some advantages against the usual one in which all the air is dealt with by the fan and forced through the inlet valves.

In the port method, Fig. 24, the exhaust for driving the supercharger leaves the cylinder through the port, and thus relieves the main exhaust valves, whilst the added air enters the cylinder through the same port. We have thus a free, *i.e.*, not under, pressure, and cool main exhaust system—cooler exhaust valves and also a free air inlet.

Whether any practical method can be evolved out of a pure fluid charging system without intermediate pistons or centrifugal impellers, may seem doubtful, but I think it worth some further investigation.

With respect to thermal efficiency, is it correct to say that this will be reduced with, say, an exhaust-driven type and not working to saturation? In the early experiments it was shown that the lower density brought lower flame temperatures and hence higher efficiencies, which were recorded in Sir Dugald Clerk's papers.

Generally, despite the fact that some engineers stick to the opinion that for ordinary land duties, it is just as effective to increase the size of the engine to get increased power, as by supercharging, it does seem that in the immediate future a big increase will take place, and most likely this will be of the exhaust-driven type, and furthermore, this seems really to be the most practical method of compounding the internal combustion engine.

In reply to the written communications, Mr. FEDDEN wrote: I am in full agreement with the Master of Sempill as to the value of the bi-fuel system, having, in fact, carried out an extensive series of bench and flight tests using this system, with excellent results from the performance point of view. Unfortunately, as far as this country is concerned, the use of alcohol fuel is considerably hampered by Excise restrictions, and the duplication of the fuel system is not looked upon very favourably by aircraft designers and pilots. I believe that the introduction of supercharging will bring up the question of the use of bi-fuel again for aircraft, and that this system, coupled to supercharging, will give even better results.

I do not consider variable pitch airscrews absolutely essential, though obviously, once suitable light types become available, I agree they will greatly enhance the performance of the supercharged engine so equipped.

At present we have supercharged engines operating with fixed propellers and giving a much increased performance over straight engines, even with high compression-ratios, while it would seem that some time must elapse before we can obtain a variable pitch propeller of reasonable weight and reliability.

I think that Major Strickland is rather confusing the issue. There are two general cases of supercharged engines. One is the specially designed engine, supercharged to obtain the maximum power, from a given cylinder capacity in

the case of a car engine, or given weight and size in the case of an aero engine; in these cases 60 to 100 per cent. increase in power is obtainable without anything like this increase in total weight. Bearing loads increase comparatively slightly with supercharge, and in most cases are not the limiting factor; for example,

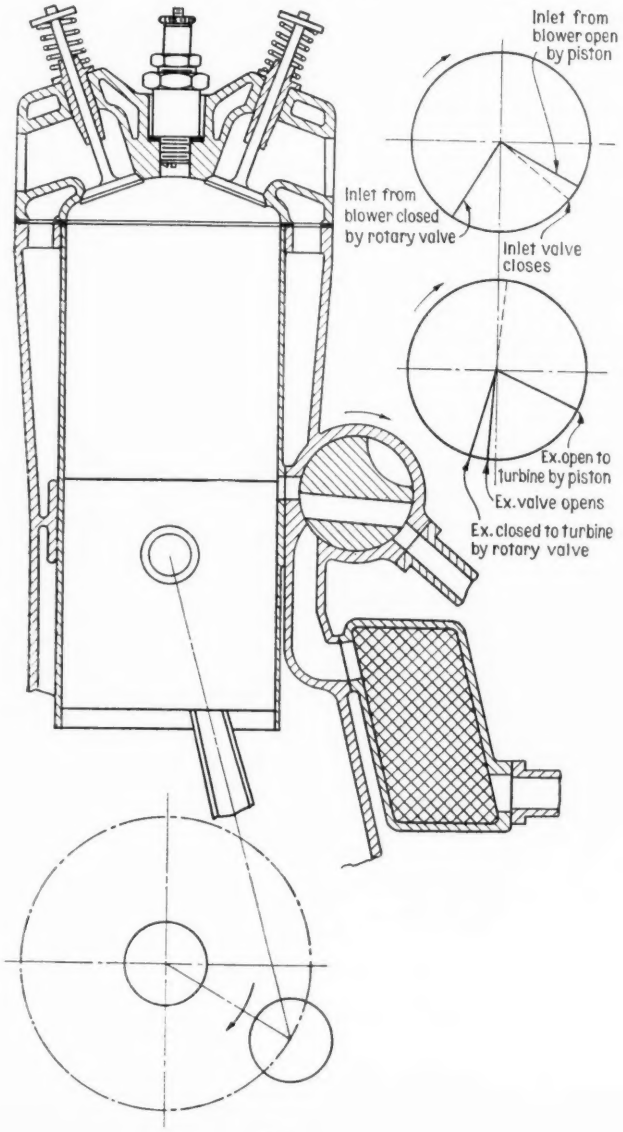

Inlet from blower open by piston
Inlet from blower closed by rotary valve
Inlet valve closes
Ex. open to turbine by piston
Ex. valve opens
Ex. closed to turbine by rotary valve

FIG. 24.

Exhaust drive for supercharger suggested by Mr. Chorlton.

in the case of a radial engine the big-end loading is actually decreased with supercharge.

In the second case we have the more conventional engine with the supercharger either in occasional use when maximum power is required, as on the average car engine, or with the supercharger used purely as a means of maintaining the normal designed output of the engine, as in the case of the aero engine, operating, as it always does operate in service, in a comparatively thin atmosphere.

Even in the case of racing, I cannot agree that engine weight is of secondary importance; for high-speed motor boats it most certainly is of primary importance.

The loss in power of naturally-aspirated aircraft engines at even moderate heights is very serious, and rules out the statement that supercharging for this class of engine is a special case.

Major Strickland's simile of the locomotives might "cut some ice" in America, where the tax on a 38 h.p. car is about £2 and petrol is 10d. per gallon, but in Europe I should say that the main object of the motor-vehicle designer during the last ten years has been to get the maximum all-round performance from the smallest possible engine.

With reference to comparative data on supercharged and naturally-aspirated engines of identical horse-power, I am afraid no such information exists on motor-vehicle engines. I submit that sufficient data are available to prove a strong case for the aircraft engine.

While not wishing to challenge such authorities as Sir Dugald Clerk and Mr. Ricardo, I submit that the form of supercharger referred to by Major Strickland is not simpler than the separate unit. There are several practical difficulties in the design, and I think it is undoubtedly heavier. In support of this view I think an apt simile is the incorporation of the electrical generating mechanism in the flywheel of a motor-vehicle engine. With the exception of the Ford, it has been found more suitable to standardise separate units for this purpose.

With regard to Mr. Chorlton's statement that "50 per cent. of the gross power increase was required to operate the supercharger," I consider that, presuming the ratio of supercharge was a reasonable one, the unit must have been very inefficient. I am afraid that I am not in a position to give him the comparative tables he requires. I would further add that in the case of aero engines, with which I am primarily concerned, the figure when supercharging at altitude would be in the neighbourhood of 20 per cent.

The piston type of supercharger is barred from consideration from the aero engine point of view, owing to the prohibitive weight and size of a suitable type.

I agree that from the thermal efficiency point of view, and where supercharging at really high altitudes is required, the exhaust-driven type is the most attractive, and its ultimate development is largely a question of materials.

SAFETY FROM FIRE IN AIRSHIPS

R38 Memorial Prize Paper, 1927

BY WING COMMANDER T. R. CAVE-BROWNE-CAVE, C.B.E., F.R.AE.S., A.M.I.MECH.E., A.M.I.N.A.

> "That immediately after the fracture a fire broke out in the forward portion, and this was mainly responsible for the large loss of life."
>
> *Extract from Finding of Court of Inquiry on R38.*

Introduction

In the tragedy of R38 it is the structural failure which happens to have attracted most attention. The tragic consequences which resulted from the structural failure were fatal almost solely because of fire.

The nature and causes of the structural failure are now well known, and in the science and art of hull design sufficient progress has been made to render future structural failure as improbable in an airship as in a ship at sea. It is fitting, therefore, that a large proportion of the essays submitted for the R38 Prize should describe work which has been done to eliminate the initial cause of failure.

The following extract from the narrative determined by the Court of Inquiry shows the part played by fire in the loss of life and the destruction of the airship:

> "The ship then broke into two portions. The forward portion caught fire at the fracture, at the moment of or shortly after separation.
>
> "The fire probably originated in a spark from the electric leads, which became fractured at a point in the immediate vicinity of a similar fracture in the petrol mains. As all sources of electrical energy were situated in the forward portion only, the rear portion was not affected, as electric leads in the latter portion became dead immediately the fracture took place.
>
> "The fire in the forward portion spread rapidly, due to the presence of escaping petrol in the keel. An explosion followed, which led to the collapse of the structure and the ignition of the liberated hydrogen gas.
>
> "A second explosion took place when the forward portion reached the water.
>
> "Meanwhile, the after portion descended comparatively slowly, but did not catch fire; four of the five survivors were in this portion, and were rescued uninjured."

It is appropriate that one of the essays offered to the memory of those who lost their lives in R38 should review the potential causes of fire in airships and the precautions which can be taken to reduce this danger to an unimportant minimum.

Acknowledgments and Disclaimer

In addition to assistance from those authorities quoted in the text, much has been derived from frequent discussion with Major Scott, with Mr. Pye, Deputy Director of Scientific Research, and with Mr. Dyer, Chief Chemist at the Royal Airship Works.

The essay arises from the author's experience as a member of both the Court of Inquiry on R38 and the Accidents Committee which held a fuller technical inquiry. He was also, until 1922, a member of the Fire Prevention Sub-Committee of the Aeronautical Research Committee.

The precautions to be taken against fire are not part of the duty with which the author is officially charged, and it must not be assumed that the opinions and conclusions expressed herein conform with the officially accepted view, or even that they necessarily have the concurrence of those with whom the author has had the benefit of discussion.

The essay represents the author's personal view at the present state of his experience and knowledge, after much investigation and the discussion of certain particular points with the best authorities to whom he had access.

The General Problem

In order to provide against the destruction of an airship by fire, it is necessary to consider the process in each of its essential stages.

There must be a source of ignition, and, brought into contact with it, a combustible mixture of gas or vapour with air.

This initial fire will only become fatal to the airship if there is a combustible connecting link by which fire can spread to a quantity of gas or fuel sufficient to cause the destruction of the airship.

An initial fire may arise from various chance causes as it does in other transport units or in buildings. An important part of the problem is, therefore, the precautions to be taken against spread of such an initial fire.

The Source of Ignition

The chief sources of ignition are an open flame, a body at very high temperature, and an electric discharge.

The exact nature of the process of initiating the combustion of an inflammable mixture is in the case of ignition by electric discharge rather obscure, but with the other sources of ignition it appears only necessary that some part of the mixture should be heated to a certain critical temperature at which combustion begins locally. That combustion generates sufficient heat to raise the neighbouring parts of the mixture to ignition point, thereby continuing the combustion.

Ignition by Flame and Hot Surfaces

Apart from flame caused by the use of matches there are other sources of initial ignition of the same character.

Lubricating oil falling on a very hot surface such as that of an exhaust pipe will catch fire, although petrol falling on the same hot surface is evaporated and passes away before it is raised to its ignition point.

The airship diesel oil at present being used, although of high flash point, forms, when falling on to red-hot metal, a vapour which is easily ignited, but which does not ignite on the surface from which it is evaporating, even if that be red hot.

Table I. shows the flash points and ignition points of typical oils.

TABLE I.

Oil.	Flash Point °F.	Ignition Point °F.
Petrol.	Below normal air temperature.	700
Special kerosene.	115	720
Airship diesel oil.	210	780
Lubricating oil.	390	750

The latent heat of the vapour formed prevents the temperature of the liquid rising above the upper limit of the boiling range. In so far as this upper limit is indicated by the flash point, and this appears generally to be correct, the table explains why, although the lighter oils falling on the hot surface never reach their ignition temperature, lubricating oil ignites because the upper limit of its boiling range is below its ignition temperature.

Fabric, rubber or wood, if not fireproofed and particularly if saturated with oil, will burst into flame if allowed to come into contact with a very hot surface.

Recent experiments made by the Accidents Sub-Committee for the prevention of fire in aeroplanes indicate that, so long as the temperature of the metal surface does not exceed 720°F. (400°C.), ignition of oils, fabric or wood will not take place although inflammable gas is given off, and could therefore be ignited if a suitable source of ignition were present.

The exhaust flame of an engine often fails to ignite a combustible mixture exposed to it. The temperature of the issuing exhaust gas is almost certainly far above the ignition point of most gas mixtures. The exhaust contains, however, a large proportion of inert nitrogen and products of combustion which may so far dilute the surrounding explosive gas mixture as to make it incapable of ignition by the front of the exhaust flame which is at a comparatively low temperature on account of the rapid loss of heat.

If the combustion in the cylinder has been much delayed, the gases may be burning vigorously as they reach the outer air. The igniting power of the exhaust flame will then be greater than if the combustion has been completed within the cylinder.

Electric "Sparks" of Alternating and Direct Current

Much research has been directed to the examination of the various forms of electric spark in relation to their power of igniting the mixtures of methane and air which occur in mines. The conclusions are probably applicable in a general way to mixtures of other hydrocarbon gases which may be found in connection with the fuel system of an airship.

For mixtures of hydrogen and air the conclusions can be less certainly applied, and very little work appears to have been published. The matter is, however, of great importance in airship development.

Professor Thornton has described (Proc. Inst. Electrical Engineers, 1924) a remarkable difference in the igniting power of alternating and direct currents when the circuits are broken rapidly so that the separating surfaces of the conductor do not become overheated.

Not only is alternating current safer in this respect than direct current, but the safety increases as the periodicity is increased.

The minimum currents which when broken in this way will ignite the most sensitive methane-air mixture have been determined for various voltages and frequencies. It is sufficient here to quote those for a circuit at 200 volts.

TABLE II.

Frequency cycles per second.	Current to cause ignition. Amperes.
direct current.	.4
20	2.4
40	3.6
60	9.5
80	14.0
100	20.0

Dr. Wheeler has shown (Safety in Mines Research Board Paper No. 20) that these differences do not exist when comparatively thin terminals, such as those of an ordinary tumbler switch, are used at the break. Under these circumstances any superiority of alternating current appears to be limited to the chance that the current will not be at the crest at the moment of break.

It is possible that, with the thin terminals, the current at break is sufficient to heat the metal to the ignition point of the mixture, whereas with the thick poles used by Thornton the cooling by conduction was sufficient to prevent that temperature being reached.

From Professor Thornton's results it may also be deduced that for a given power in an alternating current circuit the risk of ignition by a break spark is reduced if higher voltages are used.

It is probable that a live conductor gradually torn apart or pulled out of its fitting would give rise to sufficient current density at the point of parting to cause a temperature in the metal well above that necessary to produce ignition.

The danger of ignition is not, however, confined to the moment of rupture of the conductor. The end exposed by the fracture may be left sparking to the protecting conduit or to the metal structure as was the case in R38.

To avoid this it can possibly be arranged that the conductor is so much less extensible than its insulating sheath that it will break the circuit before it is exposed, and then be covered by the extended insulating material.

Colonel O'Gorman has suggested (Fire Prevention Sub-Committee of A.R.C., 1922) that parallel with the conductors should be included a piano wire of sufficient strength, and so connected as to pull open a switch in the circuit before the conductor could part or become exposed by fracture of the insulation.

In legislating for damage to conductors it is not wise to preclude serious structural damage. It is exactly at the time of a serious accident that it is most necessary that danger of ignition should not be present.

Although the greater safety with alternating current is limited to clean, quick breaks, there is nothing to indicate that direct current is safer than alternating current in the case of any form of damage to conductors.

Direct current is in certain respects the more convenient where a number of small generators are to be used in parallel, and where batteries are required to maintain essential lights in case of temporary failure of power.

The powerful flash which can be produced by accidentally short-circuiting a battery, particularly of the modern type used for engine starting, is very dangerous.

The sparks at commutators of direct current motors and generators are powerful sources of ignition. It is very difficult to make such machines satisfactorily gastight. Considerable weight is involved in the casing and the ducts for ventilating to and from the outside of the airship.

The squirrel cage motors possible with alternating current have no exposed running contact, and have very important advantages in safety.

Small switches, electric bells and sound signals are potential sources of sparks probably of the dangerous kind, and if they must be placed in positions which may be reached by a combustible mixture, require careful design and arrangement.

The filament of an electric incandescent lamp if exposed by fracture of the bulb is a possible source of ignition. Tungsten filaments are said to be less dangerous than others. The thin filaments possible with high voltage are said to be safer than those which must carry the heavier currents of a low voltage system.

Lightning

It is very difficult to obtain reliable information as to the danger caused by lightning. The German airship Bodensee was actually struck by a direct flash

which caused considerable fusion of the metal near the points of entry and exit of the discharge. The metal framework of the hull was, however, of sufficient cross-sectional area to take the current without excessive heat, except near the points of entry and exit. At these points the current density for a given discharge depends on the local thickness of the metal.

It is, however, most necessary that all metal parts should be thoroughly bonded together so that there may be no serious resistance, and therefore sparking or overheating by the passage of current.

The electric conductivity of hydrogen is about $4\frac{1}{2}$ times that of air. A lightning stroke is, therefore, if gas is being released, likely to pass down the ascending stream of hydrogen. Under such conditions the discharge, even if only sufficient to produce small local sparking where it enters the metal framework, would do so at a point where ignition of the gas would be almost certain to result.

It is not, of course, only when an actual lightning stroke reaches an airship that large currents in a structure may be produced. A lightning discharge in the neighbourhood can induce large currents in the structure. They lack the dangerous points of entry and exit and are probably harmless provided that the bonding is good.

The risk which an airship in free flight experiences from lightning is not to be compared with that of kite balloons which are secured to earth by a cable many thousand feet in length. Not only were balloons in the past often very imperfectly bonded, but their cables offered a path altogether more attractive to a discharge than would an airship of much smaller length unconnected to earth.

The mean atmospheric voltage gradient with height is, in fine weather, 300 volts/metre, and in thundery conditions may be many times that amount (A.R.C. Report E.B.6, August, 1917).

Sources of Ignition Connected with Petrol Engines

There are sources of ignition peculiar to the petrol engine which uses carburettors and electric ignition.

Damage or defect in any of the high tension leads is likely to result in an open spark of a nature quite capable of igniting an explosive mixture.

The switch wire of the primary circuit of the magneto may produce a dangerous spark at any defect.

The chance that any of these wires may be damaged near a point where a leak in the petrol system has also occurred is a considerable factor in the danger of fire.

Apart from electric apparatus, there are other sources of fire peculiar to a petrol engine.

For maximum fuel economy it is necessary to burn a very weak mixture. If the strength of the mixture is still further reduced, combustion may be so slow that it continues throughout the exhaust stroke until the inlet valve reopens. The flame then ignites the incoming mixture and passes back down the induction pipe as a minor explosion which may cause a flame to issue from the air intake.

Flame baffles are sometimes fitted in induction pipes, but they must be of sufficient mechanical strength to avoid damage by the explosion.

It has not infrequently happened that damage to a petrol pipe has caused a leakage of petrol, and also decreased the supply to the carburettor, thereby weakening the mixture and causing a flash which has ignited the leaking petrol.

The air intakes should be led outside the car through pipes of sufficient strength to resist an explosion.

Combustible Mixtures

The source of ignition or the small initial fire can only produce further combustion if there comes in contact with it a combustible gas or vapour mixed with

air in a proportion which, for each substance, must be within certain definite critical limits.

The conditions necessary for the propagation of flame are examined later in connection with gaseous mixtures, but probably apply also to the vapours given off by most solids and liquids as a preliminary to their ignition.

Certain solids such as charcoal ignite without the preliminary evolution of vapour, but they are not typical of easily inflammable materials occurring in airships.

Liquid Fuels

The flash point of a substance is the temperature at which it gives off sufficient inflammable vapour to be ignited by contact with a flame. The flash points usually quoted are those determined in a closed vessel, which is only opened to the air as the testing flame is introduced.

The rate at which vapour is given off increases as the temperature is raised. The temperature at which the fuel can be ignited when tested in the open depends upon the volume of the heated fuel, and on the extent of the surface from which the vapour is being liberated.

More important still is the flow of air over the surface of the liquid, for ignition cannot be produced until, at the source of ignition, the rate of supply of vapour is sufficient to form with the current of air a mixture within the combustible range. It is only when the fuel reaches such a temperature that its vapour pressure is equal to the surrounding atmospheric pressure that vapour is given off in considerable quantities. This is the temperature at which the first drop of liquid will distil and is often referred to as the lower limit of the boiling range. It depends, of course, somewhat on the apparatus in which it is determined.

It is sometimes suggested that this lower limit of the boiling range is better than the flash point as a basis on which to compare the relative danger of two fuels.

Any comparison of danger should properly be based on the worst conditions reasonably likely to occur. As the surface of fuel which may be exposed, perhaps by the occurrence of a leak, is in certain conditions large by comparison with the volume of the compartment in which the defect may occur, and as it is not correct to rely on any definite rate of change of air, it appears that the flash point of the fuel as determined by the closed test is the safe basis for comparison of fire risk.

The danger from a fuel only slightly above its flash point is so greatly increased when the temperature has risen to within the boiling range that some importance should be attached to this higher temperature also.

Consider the case of a surface wetted with fuel at a temperature only slightly below its flash point. A source of ignition or a small initial fire may arise from some accidental cause and produce sufficient local heat to raise part of the fuel to its flash point, and to set it on fire. The heat then produced will probably suffice to raise the adjacent fuel to its flash point, and the fire will spread.

The extension of the initial fire and what is very important, the rapidity with which the fire will extend, depends therefore on how near the temperature of the exposed fuel is to its flash point.

If the temperature of the fuel is near to the lower limit of boiling range, the spread of any initial fire is likely to be very rapid.

Consider now the numerical values for typical liquid fuels which might be used in an airship.

Table III. is the distillation record of a typical sample of aviation petrol, containing 20 per cent. benzol.

TABLE III.

The flash point is below normal air temperature.

Distillation starts at			68°F.
10%	distilled	below	158°F.
20%	,,	,,	166°F.
30%	,,	,,	176°F.
40%	,,	,,	202°F.
50%	,,	,,	212°F.
90%	,,	,,	247°F.

The flash point and lower limit of boiling range are, respectively, for high flash point kerosene 115°F. and 320°F., and for airship diesel oil 210°F. and 430°F.

An airship flying between England and India must expect to meet an atmospheric temperature of 130°F. The whole of the fuel stored in the airship and all the metal and fabric surfaces of the ship will occasionally reach this temperature.

The water-cooled surfaces of the engine will normally be at 212°F.

Parts of the exhaust pipe if not water-cooled will have a very high temperature, but will be protected by a shield which itself will not exceed, say, 400°F.

The temperature of the engine surface in relation to the characteristics of the fuel has an important bearing on the fire risk. Initial sources of fire are perhaps more likely to arise in the engine car than elsewhere. Engine vibration renders the fracture of some part of the fuel system more likely and the escaping fuel is likely to fall on to the engine or other parts at approximately the same temperature.

The comparative safety of the three typical fuels under these circumstances is therefore obvious.

Petrol, always above its flash point, will even in the storage tanks at 130°F. liberate some five per cent. of its normal volume. If it leaks over the engine the evolution of vapour will be very rapid indeed.

Kerosene will give off some vapour in storage, and if it leaks on to any surface of the ship at 130°F.; but even if falling on the engine it is still considerably below its boiling point.

Airship diesel oil, even if leaking over the engine, is only 2°F. above its flash point, and the amount of inflammable gas given off would probably be quite unimportant. The exhaust cowl at 400°F. would cause inflammable vapour to be given off, but would not supply the source of ignition necessary for fire.

In a petrol fire it is the speed with which the flame spreads which renders the fire so overwhelming. Kerosene is safer, but under the tropical conditions assumed, will probably be as dangerous as is aviation petrol on a cold day.

Heavy oil appears almost safe from ignition, and any fire which arose could probably be extinguished without difficulty.

By comparison with kerosene, petrol has one element of safety in that any small leakage will evaporate fairly quickly at ordinary temperatures. Kerosene leaking perhaps on to the outer cover would creep over a large surface and would not evaporate at ordinary temperatures. A sudden increase of temperature on reaching tropical conditions, or in the neighbourhood of an accidental fire, might cause from the accumulated leakage a greater evolution of vapour than would have resulted had the fuel been petrol.

Hydrogen and Fuel Gas

The combustible gas mixtures which might occur in an airship were formerly limited to those of hydrogen and petrol vapour with air. A proposal by the Zeppelin Company to employ gaseous fuel widens the problem to be considered.

To maintain the equilibrium of the airship it is necessary that if the fuel gas is denser than air, sufficient hydrogen must also be used to reduce the combined density to that of air.

Gas fuels must, therefore, be compared on the basis of calorific value per unit of displacement of the gas together with sufficient hydrogen to reduce its density to that of air.

On this basis it can be shown that the denser hydrocarbon gases are preferable to the lighter ones with which little or no hydrogen need be used.

If the gases are derived from an oil cracking process, it is probably costly to use only the denser fractions.

In considering gas fuel in this essay, ethane has been selected as one only slightly denser than air, and butane as the densest likely to be employed.

Burgess and Wheeler (Trans. Chem. Soc., 1911) explain that "To ensure propagation of flame it is necessary (1) that the initial source of heat should be of a volume, intensity and duration sufficient to raise the layer of gases in its immediate vicinity to a temperature higher than, or at least as high as, the ignition temperature of the mixture; (2) that the heat contained in the products of combustion of this first layer should be sufficient to raise the adjacent layer to its ignition temperature."

Brame ("Fuel") further points out that there are three factors which govern the "lower limit mixture," (1) the calorific power of the gas, (2) the relative volume and specific heat of the diluent gases, (3) the ignition temperature of the mixture.

Table IV. shows the limits of explosive range and the ignition temperatures for various gases which might be used. The values are taken from a variety of reliable sources which, however, differ somewhat among themselves. The figures must therefore be regarded as approximate, and not rigidly comparable.

TABLE IV.

Normal Temperature and Pressure.

	Density lbs. ft.^{3}	Explosive Range. Per cent. in air		Ignition Temp. °F.	Net Calorific Value BTU ft.^{3}
Hydrogen ...	.0056	10 to	66	1080	289
Methane ...	.0447	5.6	14.8	1200	954
Acetylene ...	.0727	3.0	52.0	750	1500
Ethylene ...	.0783	4.1	17.5	1000	1564
Air ...	.0809 (for comparison).				
Ethane ...	.0837	3.1	10.7	1030	1694
Propane ...		2.2	7.3	960	
Butane ...	.1570	1.5	5.7	900	
Pentane ...		1.35	4.9	880	
Benzene ...	.2235	1.5	8.0		3845
Petrol Vapour	.2820	1.5	5.3		4300

It appears unlikely that the diffusion of a gas through the fabric surrounding it would be sufficiently rapid to cause the accumulation of an explosive mixture under any conditions probable in an airship.

A comparison of the fire danger associated with leakage of fuel gas, hydrogen and petrol presents almost prohibitive difficulties.

Hydrogen leakage in the upper part of the ship is a danger common to all the schemes, but is small on account of absence from that part of the ship of electric circuits and other potential sources of ignition.

Consider now the conditions in the lower part of the hull where an accidental source of ignition is less improbable.

Hydrogen discharged from the automatic valves must, of course, be led away by gastight trunks to the top of the ship.

Except on the comparatively rare occasions when the airship is at or above pressure height, the gas inside the bottom of the bag will be at a pressure lower than the air outside. Therefore, through any hole in the fabric there will be a leakage of air inwards rather than of hydrogen outwards, and there will be no explosive mixture formed outside the bag where it might reach a source of ignition.

With fuel gas the pressure inside the bottom of the bags will always be positive, and will vary with the head of gas and the difference between the density of the gas and that of air.

If a dense gas is used, the calorific value is high, the total volume required is therefore small, and the surface of the containing bags is small. On the other hand the pressure within the bags is comparatively high.

These considerations indicate that as between fuel gases there is no great difference of risk that considerable leakage will take place. The infrequency of positive pressure in the bottom of a hydrogen bag renders a leak of hydrogen in the lower part of the airship far less probable.

Consider now the consequences of leakage of the various gases from the lower part of a gasbag. A comparison on theoretical grounds necessarily depends on a number of very arbitrary assumptions. Of these, the most doubtful relate to the pressure within the bag, the form of the leakage and the movement of the air into which the gas issues.

Practical experiment is equally dependent on the same assumptions and involves also considerable practical difficulties and delays.

While admitting the limitations of the theoretical comparison given in the Appendix, it is submitted as interesting and not inferior to such practical experiments as could be carried out within reasonable time.

The conclusion is that there is no very marked difference in the danger from an outward leak of hydrogen, light or dense fuel gas, or petrol vapour. The least problematical case considered is that of leakage into a closed space in which there is good circulation. The time taken to produce an explosive mixture is in the proportion of—

2.8 for light fuel gas (ethane).
2.5 for petrol vapour.
2.4 for hydrogen.
1.9 for heavy fuel gas (butane).

This is therefore their order of merit for leakage into a closed space.

For leakage into an open space the danger from a fuel gas of air density is about double that from hydrogen, petrol, or a dense fuel gas.

Whereas the flame of hydrocarbon gases is luminous and usually smoky, that of hydrogen is almost invisible unless other substances are burning in it. This greatly adds to the difficulty of locating a hydrogen flame and making certain that it has been completely extinguished if the supply of gas has been temporarily cut off.

It must be arranged that gas discharged from the manœuvring valves and also from the safety valves in the lower part of gasbags is led away by trunks to discharge orifices at selected positions in the outer cover. There must be no risk that this discharged hydrogen may escape into the space within the outer cover, and especially not into the lower part of that space where it may come in contact with electric conductors and other possible, though admittedly improbable, sources of ignition.

Once the gas has escaped from the outer cover, it appears unlikely, however rapidly the airship is rising, that any appreciable quantity of this gas will reach the engine cars or lower parts of the exterior of the airship.

The conclusion of this section is worth restating.

Possible sources of ignition in the hull are largely confined to the lower part. Even if a hole in the gasbag exists, it is only on rare occasions that hydrogen will reach this space, whereas fuel gas or petrol vapour are likely to reach there whenever a leak exists.

An airship using heavy oil is, therefore, very much safer than one using petrol or fuel gas.

The Influence of Ventilation or a Stream of Air

With solid fuel such as coke or charcoal a draught of air stimulates combustion. This is also true when the fuel burns largely from the solid form rather than by liberating gases and vapours.

On the other hand, if the fuel is one which largely volatilises before it burns, a violent stream of air may so disperse the vapour that the fire is "blown out."

When the quantity of inflammable vapour released into a space is in more than a certain proportion to the quantity of air present, the addition of air by ventilation or an air stream will increase the rate of combustion. For this reason a small airstream passing through an engine car may increase a fire beyond what it would otherwise be.

Under any but abnormal circumstances good ventilation of a space into which combustible vapour may be released is beneficial, as it reduces the risk that the mixture formed will reach the lowest strength which can be ignited.

In some experiments conducted for the Fire Prevention Sub-Committee of the Aeronautical Research Committee, it was demonstrated that even the unfireproofed doped fabric of an aeroplane wing if sprayed with petrol and then ignited was blown out by an airstream of less than the stalling speed of the aeroplane.

A striking example of the effect of an airstream is furnished by some experiments carried out by the author at the Isle of Grain in 1922 to demonstrate the comparative safety of petrol tanks carried under the wings of an aeroplane. The tanks were of streamline shape secured to the underside of the wing and terminating near the trailing edge. A relative wind of about 60 knots was produced by the slipstream of another aeroplane. The tank which contained petrol was punctured by a burst of incendiary bullets from a machine gun. The issuing streams of petrol were not ignited, although had the tank been sheltered within the fuselage, ignition by a single bullet would have been practically certain. The petrol was then with difficulty ignited by a flaming torch. The resultant fire was a large sheaf of flame blown by the relative wind well clear of the trailing edge. An increase of the airspeed blew the front end of the flame further aft; a decrease allowed it to approach closer to the tail end of the tank.

The absence of fire at the tank was due presumably to the time taken for the petrol to mix with sufficient air to form a combustible mixture. It was not until the eddy region was reached that the mixing became more violent and ignition could be produced and maintained.

After several repetitions of the experiment with similar tanks under the wing a tank was similarly mounted above the top plane. It is possible that the airstream was striking the top plane at more than the stalling incidence. Not only did the incendiary bullets ignite the tank immediately, but the fire extended far along the top surface of the plane in the eddy region.

Finally, a control experiment was made with a petrol tank mounted as usual within a fuselage exposed to the airstream. The resultant fire had all the overwhelming characteristics associated with an aeroplane shot down in flames.

The rate at which air is flowing past the source of inflammable gas or vapour is therefore of critical importance, not only as preventing the accumulation of a dangerous mixture in an enclosed space, but also perhaps in preventing a local concentration which may support combustion.

Engine Car Fires

The engine cars contain large surfaces at comparatively high temperatures, lubricating and fuel oil pipe systems under high pressure, the electric generator and a starting engine. The starting engine must at present be one with electric ignition, and using petrol or hydrogen as fuel.

The fires in the engine cars of earlier airships using petrol were rare. The risk of fire in modern engine cars is vastly less, but it seems certain that the engine car is of all parts of the airship the most probable seat of an initial fire.

The extinction of such a fire or its isolation from the remainder of the airship require, therefore, special consideration.

The petrol tank of the starting engine must of necessity be large and would contain enough petrol to cause a very serious fire if liberated by leakage or an explosion. It is therefore wise to arrange that the whole tank can be slipped out of the bottom of the car if fire occurs. To discharge the petrol through a ballast valve is far less safe. The issuing petrol may be ignited, or flame may be drawn into the tank as the petrol is discharged, and an explosion may result. If the tank is slipped, the quantity of petrol left in the pipes and carburettor is unimportant. There should be no petrol pipe leading to a petrol tank in the hull.

The air intake of the starting engine carburettor must be from outside the car through a pipe capable of withstanding the shock of back-fire, and so arranged that petrol flooding from the jets cannot accumulate.

If hydrogen is used it must be drawn down through a pipe at the top end of which there is a water seal so arranged that the pressure in the pipe below it is never above atmospheric, and when hydrogen is being used considerably below atmospheric. The water seal must be capable of stopping any flame travelling up the tube as a result of an inward leak of air.

The electric generators must be totally enclosed, the ventilation inlet and outlets being taken through the skin of the car. The magneto of the starting engine must be of a tested flame-proofed type.

There should be no fuel storage tank in the cars. The fuel supply pipes should be fitted with cocks, both at the upper and the engine car ends. A properly arranged drip flange fitted at a part of the pipe exposed to the full airstream will prevent any fuel leak forming a combustible link between the car and airship.

There should be no trunks connecting the car with the hull, as they would form a channel through which fire or combustible gas might pass.

It is very important that the bilge of the car should be well drained so that no oil can accumulate, and should be clear and open so that any fire there can be easily reached by the jet from an extinguisher.

Water-cooled exhaust manifolds have proved a frequent cause of mechanical failure. An air-cooled pipe can be so covered with a shield that no oil or other combustible material can reach the pipe itself. The shield should be so designed that its temperature never reaches 400°F.

The top of the engine car should have a canopy such that it will not be destroyed by fire within the car. The access hatch to the car should be self-closing so that there is no fear of its being left open if the car has in extreme emergency to be abandoned.

Fires in Other Parts of the Airship

It is difficult to discuss generally the fires which may arise in parts other than the engine cars.

The W/T station and the galley must certainly be regarded as portions in which sources of ignition will frequently exist. The ventilation inlets and outlets must be so arranged as to involve the minimum danger of introducing inflammable gas to the space, or of discharging sparks and flames to a dangerous place if fire occurs in the compartment.

These sources are not in themselves very serious provided the amount of combustible material in the compartment is so small that the worst fire which can arise is not enough to spread to other spaces, and can be certainly extinguished with the fire appliances provided.

Fire Extinguishers

The type of extinguisher to be provided requires very careful consideration, not only because the consequences of its success or failure to extinguish an initial fire may be vital, but because the conditions of its use are not always recognised.

Extinguishers using carbon tetra-chloride give very powerful extinguishing effect partly by the gas given off and partly by the latent heat of the liquid which cools the surface on which the combustible vapour is being liberated. When used in an engine car they have two very serious defects as shown in tests carried out by the author in April, 1921. Very small petrol fires were made in the bilge of an enclosed engine car. Progressively increasing amounts of petrol were used, and the fires were attacked with extinguishers of the carbon tetra-chloride type. Although very small fires were quickly extinguished, larger fires in which the quantity of petrol involved was, however, less than half a pint could not be extinguished partly on account of the effect on the operator of the gas liberated and partly on account of the dense black smoke which obscured the fire and prevented the remainder of the extinguishing liquid being satisfactorily aimed.

The effect of the fumes on the eyes and throat and the obscuring effect of the black smoke rendered the operator helpless even had it been possible for him to remain in the car without being gassed.

Experiments with more suitable extinguishers are in progress and are proving very satisfactory, but it is desirable to record these earlier trials as indicating the necessity of testing any proposed extinguisher under the conditions in which it will be used.

Heavy Oil Fuel

The selection of a suitable oil fuel requires a compromise. From the foregoing considerations it is clear that any increase in the flash point is accompanied by an important decrease of fire risk. On the other hand, it is probable that the airship will occasionally encounter atmospheric temperatures as low as 0°F. and the oil must continue to flow satisfactorily in the pipe system under these conditions.

The thickening of fuel oil at low temperature is largely due to the solidification of wax crystals. The removal of this wax would greatly increase the cost of the oil. The only way to delay their formation is to retain in the oil certain of the lower boiling fractions which, although they help to retain the wax in solution, do also lower the flash point.

There appears to be very little published work on the calculation of the flow of viscous oil through pipes. A section of a pipe system including shut-off cocks and a gauze filter was therefore erected in a cold chamber which could be reduced to 0°F. Several samples of oil were tested under these conditions, but it would be expensive to make routine tests in this way. Sufficient information was, however, gained with different types of oil to connect empirically the actual flow through a cold pipe system with tests which can conveniently be made in the laboratory.

It appears quite possible to obtain from a variety of sources and at reasonable price oil with a flash point of 210°F. which will flow satisfactorily at temperatures approaching 0°F.

Helium

There remains the question whether the use of helium would give still greater safety. Opinion on this must be largely speculative.

The author considers that in the light of present knowledge it is probable that a military airship filled with helium would, by comparison with one using hydrogen, lose so much in speed, range and ceiling that her risk of destruction by the enemy before achieving her objects would be the greater.

For commercial airships, even if the cost of helium is not in itself prohibitive, reasonable performance could only be achieved by such reductions of strength, decrease of allowance of ballast and spare fuel, and increased reluctance on the part of the pilot to release gas in emergency that the hazards therein implied would far outweigh the risks remaining in a hydrogen-filled airship, provided that heavy oil is the fuel employed.

The Assumed Scale of Damage

The destruction of R38 indicates clearly that when taking precautions against fire, it is not sufficient to provide only for normal occurrences or small damage. A fracture similar to that of R38 is in the future highly improbable.

The airship may collide with the mast in thick weather, or be driven to the ground by extreme stress of weather, or an airscrew may burst. The consequences are comparatively unimportant provided that although she has sustained serious structural damage she does not catch fire.

An Atlantic liner is very safe so long as she does not sink. Until the Titanic sank after collision with an iceberg, liners were only made safe against minor damage and injury to the bottom by stranding.

The provision made in R38 against fire and in the Titanic against sinking did not provide for serious damage.

There must occasionally be airship wrecks, rare in future no doubt, as are wrecks of seagoing ships, but the chance that they will occur is sufficient to necessitate fire precautions which will be effective even in the case of serious damage.

General Conclusion

It appears certain that an airship using heavy oil is, beyond all comparison, safer from destruction by fire than were former ships using petrol. Not only is the danger of initial fire less, but the bulk fuel storage is practically proof against fire. In the absence of fire in the fuel storage system it is very unlikely that an accidental fire would spread to the hydrogen, and thereby become fatal to the airship.

The proposal in Germany to use gaseous fuel involves, in the opinion of German engineers, a smaller risk of fire than does petrol. It does, however, in the author's opinion, involve a greater risk than that connected with hydrogen. Such an airship is, therefore, less safe than one, also hydrogen filled, but using heavy oil fuel.

APPENDIX

A Comparison of the Danger Caused by Leakage of Various Combustible Gases

Consider the leakage through a hole under a small constant difference of pressure.

The velocity of flow through the hole is $K/\sqrt{\rho}$ where K is a constant and ρ is the density of the gas.

Let Q be the ratio, by volume, of gas/air at the lowest limit of the explosive range. Let a be the radius of the leak hole, and let r be the radial "danger distance" from the hole at which the concentration Q exists.

Immediately at the leak hole the gas mixture will be too strong to ignite. Then as the distance from the hole increases, the upper limit of the explosive

range will be reached. At a point outside this limit but within the radial distance r, at which the lower limit of the explosive range is assumed to exist, ignition can be produced by a suitable source. Outside r the mixture will be too weak to ignite.

Case 1

If the gas is leaking into a compartment in which the air is circulating rapidly, but is not being changed from outside, danger will be reached as soon as the gas which has passed through the leak is sufficient to raise the air in the compartment to Q, the lower limit of the explosive range.

This time is proportional to $Q\sqrt{\rho}$ and is shown for selected gases in column 4 of Table A. This factor also represents the period in which the gas in the compartment must be changed in order to avoid the accumulation of an explosive mixture. The longer this period, the safer the gas. The order of merit is shown at the side of column 4.

Case 2

The speed with which gas having escaped from the leak will disperse in the atmosphere is, if there are no eddies or convection currents, inversely proportional to the density of the gas, pressure and temperature being assumed constant.

Outside a small distance from the hole eddies and currents, set up partly by the motion of the air and partly by the difference of density of the gas and air, will produce mixing many times faster than that due solely to the molecular velocity.

(*a*) If the velocity of mixing be assumed equal to V and uniform for the various gases,

Mass flux through the hole is

$$\pi.a^2.K\sqrt{\rho} \text{ where } K \text{ is a constant.}$$
$$= V.A. \text{ where } Q = A\sqrt{2\pi r^2}$$
$$\text{hence } r^2 - a^2 = K\sqrt{V.Q.\sqrt{\rho}}$$

(*b*) The mixing currents are likely to depend greatly on the difference of density of the gas and air. Assume, therefore, that the velocity of mixing is

$$V_1(\rho_a r \rho)$$

$$\text{as above } r^2 - A^2 = K\sqrt{V_1\,(\rho_a \to \rho)\,Q\sqrt{\rho}}$$

Values of r/a are given in Table A, those according to assumption 2 (*a*) in column 5, and those according to assumption 2 (*b*) in column 6.

The numbers in column 5 are comparable among themselves, but not with those in column 6, which are only comparable among themselves.

The greater the value r/a, the greater the danger space surrounding a leak of given size. The order of merit on each assumption is therefore as shown at the side of each column.

Of the gases selected, ethane is typical of the lighter fuel gases, butane is the heaviest probable, petrol vapour has been introduced for comparison.

Petrol is usually carried in liquid form, and will leak as such, but this does not vitiate the comparison, provided that a is not regarded as the radius of the liquid leak.

TABLE A.

1	ρ. 2	Q. 3	Time to make explosive mixture in closed space, $Q\rho$. 4	Order of merit.	Danger distance, r/a. Assumption 2 (*a*). 5	Order of merit.	Assumption 2 (*b*). 6	Order of merit.
Hydrogen ...	5.6	10	238	3	6.5	3	2.2	2
Ethane ...	83.7	3.1	282	1	5.05	1	4.58	4
Butane ...	157.0	1.5	188	4	7.3	4	2.46	3
Petrol Vapour	282	1.5	252	2	6.3	2	1.67	1

Case 1 is based on a reasonably probable assumption.

Case *2a* and *2b* show totally different orders, and of these *2b* appears the more probably correct, although the order of *2a* is the same as that of Case 1.

AN HISTORIC PICTURE

BY LIEUT.-COLONEL W. LOCKWOOD MARSH.

Of all the treasures accumulated by the Society in the course of its long career, in some ways the most interesting is the oil painting depicting a river scene with a balloon overhead, which hangs in the Secretary's room. In spite of this I have never seen any account of it, and all trace of the means by which it came into the Society's possession seems now to be lost—unless by chance this note may catch the eye of someone still living who has knowledge of the facts. At first sight it seems to be merely one of the many fanciful pictures of a balloon ascent so common at the end of the XVIIIth century in the period immediately following the invention of the balloon, but some years ago I stumbled, more or less by accident, on certain facts that lift it out of the ruck. When I was, in 1924, collecting the material for my book, *Aeronautical Prints and Drawings*, I came across an engraved portrait of Joseph Michel, the elder Montgolfier, joint inventor of the balloon. Below the portrait in the print (which for reference purposes I may mention is reproduced in Plate 3 of my book) is a small oval picture which, as soon as I saw it, struck me as being vaguely familiar. Glancing casually one day at the oil painting mentioned above—which was then "skied" over one of the doors in the Library—I at once noticed a resemblance to the other picture in the print, and a close comparison between the two revealed the fact that though not absolutely identical—in such cases they seldom are—the resemblance was sufficiently exact to leave little doubt that the painting was the original from which the engraving was taken. This was of itself interesting, but a certain "look" about the picture reminding me of several in the collection of Sir Mortimer Singer led me to take the painting to the light and examine it under a magnifying glass, when I was rewarded by finding at the foot in the centre the faint signature, in red paint, "de Lorimier." To anyone who has studied early ballooning literature or prints this, of course, at once let in a flood of light.

The Chevalier Charles de Lorimier appears on the scene at a very early stage in the development of ballooning. Fanjes de Saint-Fond relates (*Description des Expériences de la Machine Aérostatique*) how immediately after the ascent of the first hydrogen balloon in Paris, on August 27th, 1783, it became the fashion to construct small replicas of it, most of which were failures owing to the difficulty of finding a material sufficiently impermeable to the gas. The problem was solved by the adoption of goldbeater's skin for the purpose, which he says was first suggested by a Monsieur Deschamps, of Neufchateau; and he relates how Deschamps brought him—apparently some time between the 10th and the 19th of September—a goldbeater's skin balloon he had made, which Saint-Fond filled with hydrogen made from zinc and "acide marin" (? sulphuric acid) and released in the presence of "M. le Chevalier de Lorimier" and others. It is interesting to note that Deschamps seems to have been a painter, which may account for Lorimier's presence.

That Lorimier's interest in the subject did not stop there is shown, if we did not know it from other evidence, by the fact, as Saint-Fond again records, that he was among the first to arrive, of those who had followed its course, on the scene of the descent at Vaucressor of a hot-air balloon carrying three animals sent up from Versailles on September 19th, 1783. Without going further we have therefore very definite evidence that the Chevalier de Lorimier was familiar

with the early balloons and intimate with those who were connected with them. It is important to be assured of this for upon him we depend for much of the details of the actual appearance of them, through a series of 15—or possibly 16—small water-colour drawings he did of various of the early French balloon ascents. Most of these drawings are carefully preserved in a small room devoted to ballooning—arranged by Monsieur Charles Dollfus—in the Musée Carnavalet, the Paris equivalent of our London Museum. All, or at any rate the majority, of them were engraved by N. de Launay and issued, in both the coloured—in which condition they are extremely rare—and uncoloured state, four of these prints being used by Saint-Fond to illustrate his book. It has always surprised me that no mention of Lorimier is to be found in Bryan's *Dictionary of Painters*, for these sketches are very charming, and the mere fact that de Launay should have considered them fit subjects for engraving is some evidence of their merit.

The Society's example of Lorimier's art has a further intrinsic interest of its own from the fact that it is intended—as appears at once from the lettering on the print—to represent the two greatest achievements of Joseph Montgolfier, of which the invention of the balloon was, of course, one. At the right hand side of the picture, when one is facing it, will be noticed a pipe-line running up the cliff and all the appurtenances of a pumping station. This is a reference to the fact that, as the engraving records, Montgolfier's other claim to immortality was the invention of the hydraulic pump. I have little doubt that the landscape portion of the picture depicts with approximate accuracy the surroundings of one of the Montgolfier family's paper works at Voiron, near Grenoble—where the first hydraulic pump was installed—and that the river in the foreground is the Morge, a tributary of the Isère.

(NOTE.—I have made inquiries of Major F. S. Baden-Powell, who informs me that he bought the picture at an auction sale because he thought it interesting and with no idea at the time of its historical value.—EDITOR.)

BRANCH NOTICES

LEEDS BRANCH

Lecture Programme

Nov. 11th (Friday).—Sir Sefton Brancker, "Progress in Commercial Aviation."

Nov. 28th (Monday).—Professor B. M. Jones, M.A., F.R.Ae.S., "The Control of Stalled Aeroplanes."

Dec. 9th (Friday).—Mr. Robert Blackburn, "Manufacture of Aircraft."

Jan. 27th (Friday).—Captain F. G. Wayman, "A Synopsis of the History of Aviation."

Feb. 17th (Friday).—Major Rennie, "The Problem of the Long Range Flying Boat."

All Lectures begin at 7.30 p.m.

ASSOCIATE FELLOWSHIP EXAMINATION PAPERS, 1927

Subject: MATHEMATICS.

MORNING.

Time: Three hours.

1. A compound pendulum, the weight of the bob and arm being W and l the distance of the centre of gravity from the point of suspension, oscillates under gravity from an initial position of rest and with angular displacement a. The medium exerts a resistance on the pendulum bob only, proportional to the velocity. Determine the rate successive amplitudes of vibration diminish.

2. What is precession of a gyroscope? How do you determine the rate of precession?

3. A flat equilateral steel plate, hinged at the base, and sloping at 30° to the horizontal, covers an opening under water. The hinge is 10 feet below the surface of the water and the apex of the plate is on the surface. What is the vertical force on the apex required to open the plate?

4. Explain how to find the volume of the solid formed by the revolution of a given curve about an axis.

   Find the volume of the solid formed by the revolution of the curve $x^2+y^2-2x+2y=2$ about its centre.

5. Integrate

$$\int x^4 dx/(x-1)^2 \,.\, (x^2+4) \qquad \int_0^{\pi/2} \cos x dx/(1+\sin x)(2+\sin x)$$

$$\int (x+b)\,dx/(x^2+a^2)^{\frac{1}{2}} \qquad \int \sin mx \sin nx dx$$

6. Find the relation between the Moment of Inertia about a point in a solid body and the Moment of Inertia about three mutually perpendicular axes meeting in that point.

7. What is meant by Cardan's solution?

   What is the real root of the equation—

$$y^3+23y^2+74y+280=0$$

8. Solve, by graphical methods—

$$10x+3y=4$$
$$10y+3x=14$$

   Why cannot the following equations be solved graphically?

$$x+4y=5$$
$$.3x+1.3y=1.6$$

9. The cost of running an aeroplane is given by the equation

$$C=K+S^3/2000$$

   where K is a constant and S is the speed in miles per hour. Find the value of S which is most economical for a journey of 1500 miles, and compare this with the cost at a speed of $S+14$ miles per hour.

AFTERNOON.

Subject: MATHEMATICS.

Time: Three hours.

1. A vertical helical spring, whose weight may be neglected, is extended 1.5 inches by an axial pull of 150 lbs. A weight of 275 lbs. is attached to it and the spring is set vibrating axially. Find the time of a complete vibration. If the amplitude of the oscillation is 1.75 inches, find the kinetic energy when the weight is $\frac{3}{8}$ inch below the central position.

2. The weight of the wheel of a gyroscopic top is $1\frac{1}{2}$ lbs. and the radius of gyration 0.13 foot. It precessed 1.5 r.p.m. when a weight of 0.080 lbs. was hung on the gyroscope at a radius of 0.175 foot. Find the speed of rotation of the wheel.

3. Find the centre of pressure of an irregular-shaped flat plate immersed in water at an angle θ to the horizontal.

4. Determine the volume of the prolate spheroid formed by the revolution of the ellipse $x^2/4 + y^2/9 = 1$ about the x-axis.

5. Integrate

$$\int (x+a)\,dx/x^2(x-a)(x^2+a^2) \qquad \int_0^{\pi/4} dx/(\cos^4 x - \cos^2 x \sin^2 x + \sin^4 x)$$

$$\int (x^2+1)\,dx/(x^2+4)^{\frac{1}{2}} \qquad \int \cos mx \cos nx\,dx$$

6. Define Moment of Inertia and find the moments of inertia of a rectangle about a diagonal as an axis, a scalene triangle about its base, and a circle about a point outside its circumference.

7. Determine the two real and the two unreal roots of the equation—

$$y^4 + 27y^3 + 116y^2 + 576y + 1120 = 0$$

8. Plot the curve

$$y = x^2 + 4x - 18$$

from $x = -10$ to $x = +10$

9. A cylindrical aeroplane tank holds 400 gallons of petrol. Find the dimensions so that the minimum amount of metal plate is used in its construction, assuming the specific gravity of petrol is unity.

Subject: METEOROLOGY AND AIR NAVIGATION.

Time: Three hours.

Six questions only to be attempted, three of which must be taken from Section A and three from Section B.

A.

1. Describe how the wind speed and direction normally vary with height between the ground and a level of 1500 feet above it. How does the average variation depend on the time of day?

   How could you obtain an estimate of the wind speed and direction at a height of about 1500 feet above sea-level at a given place from a synoptic weather chart?

2. Describe briefly the principle of the Altimeter.

A pilot flies from Croydon to Renfrew, having set his altimeter to zero at aerodrome level before leaving Croydon. Assuming that the mean sea-level pressure at Croydon when the altimeter was set was 1020 millibars, what will be the actual height of the aircraft when over Renfrew if the altimeter reads 2000 feet, assuming a mean sea-level pressure there of 1000 millibars and ignoring any correction for the temperature of the air? (Height of Croydon = 230 feet; height of Renfrew = 35 feet.)

3. What are the conditions favourable for the formation of fog

(*a*) In the Western part of the English Channel?
(*b*) At a low-lying inland aerodrome?

What part does turbulence play in the formation of the fog?

State in each case the season of the year and the time of day when fog would be most likely to occur.

4. What is a line squall? Describe the main features of wind and weather which occur at a station when a line squall passes over it. What are the indications on a synoptic weather chart from which the occurrence of a line squall at a given place can be anticipated?

B.

5. Write brief notes on the following:—

(*a*) Air speed.
(*b*) Convergence of meridians.
(*c*) Position line.
(*d*) Rhumb line.
(*e*) Fix.
(*f*) Conversion angle.
(*g*) Artificial horizon.

6. Describe briefly the principle and construction of the Aperiodic Compass.

In what circumstances should the compass in an aircraft be swung for compensation of deviation?

7. Describe any method of determining the position of an aircraft by radio-goniometry, giving an example and illustrating your answer by a diagram.

What is meant by "Quadrantal Error"?

8. Describe three methods of determining the velocity of the wind whilst in flight. Illustrate your answer by examples, giving diagrams.

Subject: HEAT ENGINES.

Time: Three hours.

Answers expected to at least Six Questions.

1. (*a*) State the ideal efficiencies of the Otto cycle in terms of compression ratio and ratio of specific heats at constant volume and constant pressure.

(*b*) What difference does throttling make to indicated thermal efficiency and to brake thermal efficiency? Give reasons for your answers.

(*c*) The indicated thermal efficiency of an engine is found to be less than the ideal efficiency expressed as in (*a*) above. Explain why this is the case.

2. An engine develops 100 i.h.p. at a compression ratio of 5 to 1, and uses .5 lb. of fuel per i.h.p. hour. What power will it develop at a compression ratio of 9 to 1 and what will be the fuel consumption? If the same increase of power is to be obtained by supercharging, what pressure increase above atmosphere is required and what will be the rate of fuel consumption?

3. Define H.U.C.R.

Petrols obtained from different sources have not the same H.U.C.R. values. Why is this? Distinguish between pre-ignition, auto-ignition and detonation. State two theories to account for the action of metallic dopes in delaying detonation.

4. A certain fuel which cannot be used in a carburettor engine at compression ratios greater than 5 to 1, can be used in a solid injection or a Diesel engine at a compression ratio of 15 to 1. Explain the reasons for this difference.

5. Distinguish between the properties of castor oil and mineral oil. In what circumstances would you prefer to use castor oil?

6. What is the effect of altitude on the power of an aero-engine? Describe any one method by which the measurement of the power at altitude has been attempted.

7. Compare the advantages and disadvantages of air-cooled and water-cooled engines for use in aeroplanes.

8. Show how the torque curve of a rotary engine is affected by the inertia of the moving parts.

9. What is meant by "want of balance"? Discuss the case of a twelve-cylinder Vee engine.

10. Compare the properties of petrol, benzol and alcohol for use in an aero engine. What would be the relative powers developed and the fuel consumptions of the same engine when run with these fuels?

11. What properties are desirable in a carburettor? Describe any one type and explain the factors on which the performance depends.

STRENGTH OF MATERIALS AND THEORY OF STRUCTURES.

Time allowed: Three hours.

Eight questions to be attempted.

1. Describe with sketches, either
   (*a*) A machine for testing the hardness of metals, or
   (*b*) An impact testing machine.

2. A cantilever of length L carries a uniform load of intensity w over the half span between the wall fixing and the centre of the beam. Calculate the deflection of the free end in terms of the flexural rigidity EI.

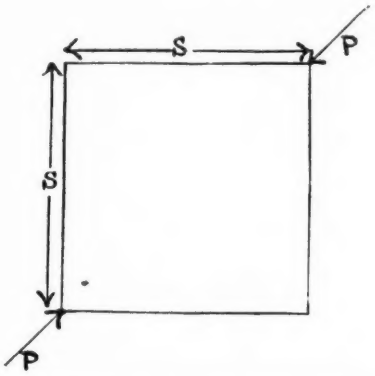
3. A steel bar 12 inches long is circular at every section. For a length of 4 inches it is 2 inches in diameter and then changes suddenly to $1\frac{1}{2}$ inches, which size is maintained for another 4 inches. The remainder of the bar is 1 inch in diameter. If the stress at the limit of proportionality for the material is 12 tons per square inch, calculate the diameter of a uniform circular bar 12 inches long which would have the same proof resilience. What is the value of this resilience?

4. A round steel bar 1 inch in diameter and 10 feet long has a load of 1 ton dropped on its end from a height of h inches so as to produce an axial stress of 6 tons per square inch. Calculate the value of h. Prove any formula you use.

5. A circular shaft of 3 inches diameter is subjected to a bending moment of 15,000 inch-lbs. and a torque of 25,000 inch-lbs. What is the maximum intensity of direct stress in the material?

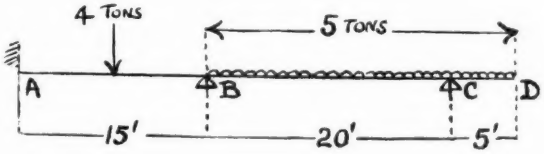
6. Explain clearly the distinction between the term "Factor of Safety" as used in standard engineering practice and the term "Load Factor" used in aeronautical engineering. Illustrate the importance of the distinction by the case of a flexible laterally loaded strut.

7. The square frame shown has stiff corners and the sides are formed of bars with a constant flexural rigidity, EI. Plot the bending moment diagram for the frame under the action of a pair of equal loads as shown in the diagram.



8. The beam shown is encastre at A, and freely supported at B and C. A load of 4 tons acts at the centre of the bay AB and the section BCD carries a load of 5 tons uniformly distributed.

Plot the bending moment diagram for the beam.



9. Describe in detail any method you have used for determining the stress distribution in a redundant frame work. What are the fundamental assumptions in your method?

10. At a certain point in a member the stresses are as follows:—

(*a*) A tension of 2 tons per square inch.

(*b*) A compression of 3 tons per square inch at right angles to (*a*).

(*c*) Complementary shear stresses of $1\frac{1}{2}$ tons per square inch acting in the directions of (*a*) and (*b*).

Calculate the maximum and minimum principal stresses at this point and also the maximum shear stress.

Subject: AERODYNAMICS.

Time: Three hours.

Answer Six questions.

1. Describe a full-scale experiment whereby the drag of an airship may be calculated. State in what terms it is convenient to express airship drag, then on the assumption that this relation can be reduced to the form $R=\lambda V^2$ where λ is a constant, show (neglecting the drag of the propellers and the virtual mass of air moving with the airship) that as a result of a deceleration test

$$\lambda = \{ W/gV_0t \} (V_0/V - 1)$$

where W = Weight of the airship.
V_0 = Velocity at any instant.
V = Velocity at time t.

In a deceleration test of a certain rigid airship the following velocities were observed after the engines had been switched off:—

t secs. ...	30	50	70	90	110	130	150
V ft./sec...	85	51	36	28.5	23	20	16.5

Discuss the constancy of λ from these figures.

2. Explain the phenomenon of auto rotation and show how this may be very simply demonstrated in a wind channel.

Obtain an expression for the couple causing the rotation of a model aerofoil, and for a given average angle of incidence indicate how its speed of rotation may be deduced from the aerodynamic characteristics of the aerofoil.

3. Describe the construction and uses of a Chattock tilting pressure gauge and show that the instrument does not need calibration.

In a particular instance a gauge filled with brine of specific gravity 1.06 has the following dimensions:—

Distance between cup centres	26.02 ins.
Distance between pivot and axis of table spindle ...	19.95 ins.
Pitch of thread on spindle	0.025 ins.

The instrument is connected to a Pitot tube in a current of air having indicated speed in the region of 45 ft.-sec. Calculate the number of turns it would be advisable to give the table spindle before opening the cock connecting the gauge with the Pitot tube.

4. Neglecting rotational inflow, show in a diagram the forces acting on an element of an airscrew blade.

Prove that the efficiency of the element is given by

$$\{ 1/(1+a) \} \{ \tan \phi / \tan (\phi + \gamma) \}$$

where a is the inflow factor, ϕ and γ having their usual significance.

In the analysis of an airscrew the following data were used for two sections D and E of the blade:—

Section.	D	E
Radius ft.	2.43	3.03
ϕ	22° 42′	18° 31′
α	4° 0′	3° 11′
D/L	0.0517	0.0484

Forward speed of machine	65 m.p.h.
Rotational speed of airscrew	1050 r.p.m.
Inflow factor	0.17
Tip radius	4 ft.

Calculate the approximate efficiency of the airscrew.

5. Deduce an expression for and show how to evaluate the drag coefficient K_D of a cylinder as obtained from pressure plotting over a cross section.

In the case of a finite cylinder discuss the accuracy of K_D thus obtained.

Sketch the type of pressure distribution in the form of a polar diagram.

6. Prove from first principles that the thrust, torque and efficiency of an airscrew are each functions of V/nD. Hence, show by means of diagrams how the complete performance of an airscrew may be represented.

7. Deduce the law of corresponding speeds as applied to two similarly shaped bodies, and show that it cannot be *directly* applied to determine the forces on full-scale aircraft by means of a model.

A length of aeroplane bracing wire of enlarged section 0.3 ins. thick and fineness ratio 3 was tested in a wind channel and gave the following results at zero yaw:—

I.A.S. ft./sec. ...	30	35	40	45	50
K_D	0.050	0.044	0.041	0.038	0.036

Estimate the drag of 50 ft. of similar bracing wire 0.06 ins. thick at an altitude of 10,000 ft. at an indicated speed of 125 m.p.h.

Air Density—
At ground level 0.00243, at 10,000 ft. 0.00175 slug/ft.^{3}

Kinematic Viscosity—
At ground level 0.000159, at 10,000 ft. 0.000200 ft.^{2}/sec.

8. In the performance calculation of a biplane the h.p. available for level flight at 800 ft. ($\sigma = 1$) allowing for airscrew effects was as under:—

V m.p.h. ...	44	61	75	86	95	104	107	112	117
h.p. ...	84	106	118	124	127	126	115	95	73

The biplane characteristics are:—

K_L ...	.049	.097	.146	.195	.292	.390	.487
L/D ...	7.33	12.47	15.67	17.15	13.49	11.17	6.39

Extra to aerofoil resistance at 100 ft./sec.

72 lbs. and 33 lbs. in and out of the slipstream respectively. Total wing area 417 ft.^{2}. Total weight of machine 2,750 lbs. Obtain the approximate range of flying speeds and the maximum rate of climb.

9. Outline a rapid method of providing for adequate longitudinal stability of an aeroplane.

Show that for a small disturbance when flying horizontally the rate of change of pitching moment M' due to the tail with respect to the main plane incidence is given by

$$dM'/d\alpha = (S'l dK'_L/d\alpha')(1 - d\beta/d\alpha)\rho V^2$$

where the accented terms refer to the tail and β is the downwash angle, l the distance between the C.G. and C.P. on the tail.

For a large biplane flying horizontally at $\alpha = 3°$, $dM/d\alpha$ for the main planes and body is instantaneously 200 ρV^2 for a longitudinal disturbance.

Given that $dK'_L/da=0.033$, $d\beta/da=0.55$ and $l=38$ ft., find the approximate tail area required in order that the aeroplane may be just stable at this angle of incidence.

10. Discuss briefly *either* of the following topics:—

(*a*) The control of aeroplanes at low speeds.
(*b*) The variation of engine power with height.